UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES

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Dedicated

to my

family,

friends

& teachers

Acknowledgement

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Dr Didar Singh

ABBREVIATIONS

3T	3 Tesla
ADC	Apparent diffusion coefficient
CT	Computed tomography
DTI	Diffusion Tensor Imaging
DWI	Diffusion weighted imaging
EMG	Electromyography
FoV	Field of view
HRUS	High resolution ultrasound
MIP	Maximum Intensity Projection
MRI	Magnetic Resonance Imaging
MRN	Magnetic Resonance Neurography
NCV	Nerve Conduction Velocity
PD-FS TSE	Proton density fat saturated turbo spin echo
SI	Signal Intensity
SNR	Signal to noise ratio
STIR	Short Tau Inversion Recovery
T2WI	T2 weighted Image
USG	Ultrasonography

ABSTRACT

Introduction : Extracranial peripheral nerve disorders may be caused by many conditions, including entrapment syndromes, trauma, masses, and acquired and hereditary demyelinating polyneuropathies. Accurate diagnosis of peripheral nerve disorders is important to guide correct patient management. This is usually performed by history taking, clinical examination, and electrodiagnostic studies. However, in some cases, clinical and electrodiagnostic studies are indeterminate. MR Neurography (MRN) enables direct visualization of nerves and can aid in diagnosis, characterization, and localization of peripheral nerve disorders.

Aim of study: 1) To evaluate the spectrum of focal peripheral nerve pathologies on MR Neurography 2) To correlate the MR Neurography abnormalities with Nerve Conduction Velocity studies and/or Electromyography findings. 3) To correlate the MR Neurography abnormalities with Surgical and/or Histopathological findings wherever possible.

Materials and Methods: This prospective study was conducted over a period of one and a half years starting from 15 September 2022 to 8 March 2024 on 58 subjects with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the department of Radiodiagnosis and Imaging, DMCH, Ludhiana. The MRN diagnosis was compared with NCV/EMG diagnosis in all the patients and with Surgical/Histopathological findings wherever possible.

Results: A wide spectrum of peripheral nerve pathologies was depicted in our study. MRN showed a high sensitivity of 98.04% with an average specificity of 71.43% and an overall diagnostic accuracy of 94.83% in diagnosis of peripheral nerve pathologies. The calculated MRN sensitivity for diagnosis of brachial plexopathies was 95.4% with a low specificity of 33.3% and a diagnostic accuracy of 88%. Surgical findings were concordant with MRN diagnosis in all the five patients who underwent surgical management.

Conclusion: MRN is an excellent highly sensitive tool for evaluation of peripheral nerve pathologies. The correlation with NCV studies and intraoperative findings further validates its clinical utility. 3T MR Neurography should be considered a key imaging modality in the diagnostic workflow for peripheral nerve pathologies. MRN serves as a roadmap for planning therapeutic interventions and is very helpful in prognostication in various subsets of patients.

Keywords: MRN, NCV, EMG, Peripheral nerve pathologies, Brachial plexus.

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INTRODUCTION

The peripheral nervous system, comprising nerves outside the brain and spinal cord, plays a central role in transmitting signals between the central nervous system and various organs, muscles, and tissues throughout the body. However, conventional imaging modalities such as X-ray, computed tomography (CT), and standard Magnetic Resonance Imaging (MRI) often fall short in adequately visualizing these delicate structures, leading to diagnostic challenges and suboptimal patient care. High Resolution 3 Tesla(T) MRI Neurography (MRN) addresses this limitation by employing advanced imaging sequences and techniques tailored to enhance the contrast and resolution of peripheral nerves, thereby enabling comprehensive assessment of nerve morphology, integrity, and pathology.

MRN has evolved as a powerful diagnostic tool in the field of neuroradiology, enabling radiologists and clinicians to visualize and assess peripheral nerve anatomy and pathology with unprecedented detail and accuracy. Unlike conventional MRI techniques that primarily focus on imaging soft tissues such as muscles and organs, MRI neurography specifically targets nerves, providing invaluable insights into various neurological conditions, including nerve entrapments, tumours, traumatic injuries, and neuropathies[1,2].

The application of MRI neurography has significantly advanced our understanding of peripheral nerve disorders, allowing for early detection, precise localization, and tailored treatment strategies. By non-invasively visualizing nerve morphology and pathology, MRI neurography aids clinicians in making informed decisions regarding patient management, thus improving outcomes and enhancing overall patient care.[3]

The development and refinement of MRI neurography techniques have been facilitated by advancements in MRI hardware, software, and imaging protocols. High-resolution imaging sequences, such as three-dimensional (3D) nerve tractography and diffusion-weighted imaging (DWI), have greatly enhanced the sensitivity and specificity of MRI

neurography, enabling the detection of subtle nerve abnormalities that were previously undetectable with conventional imaging modalities.[4]

Moreover, the integration of advanced post-processing algorithms and machine learning algorithms has further augmented the diagnostic capabilities of MRI neurography, enabling automated segmentation, quantitative analysis, and pattern recognition of nerve structures and pathologies.

Peripheral neuropathy, a result of damage to one or more nerves located outside of the brain and spinal cord (peripheral nerves), often causes muscle weakness, numbness, tingling and pain in the affected area, usually in the hands and feet. It can also affect other areas and body functions including digestion, urination and circulation. A common cause of peripheral neuropathy is diabetes, but it can also result from traumatic injuries, infections, peripheral nerve tumors and exposure to toxins. Extracranial peripheral nerve disorders may also be caused by many other conditions, including entrapment syndromes, trauma, masses, and acquired and hereditary demyelinating polyneuropathies.

The overall global prevalence of traumatic peripheral nerve injury is approximately 5%, which includes brachial as well as lumbar plexus injuries[5]. Traumatic injuries of the nerves usually occur after occupational and road traffic accidents, commonly involving the middle-age group people[6]. Peripheral nerve injury is recognised as an important cause of disability, usually leading to reduced muscle strength and loss of proprioceptive and tactile sensations[7]. The median and radial nerves are commonly injured nerves in upper limbs whereas in lower limbs, trauma affects the sciatic and peroneal nerves most often.

There are two major classification systems for nerve injury grading that are widely in practice i.e. Seddon classification and Sunderland classification[8–11]. While Seddon classification is relatively simpler to follow and more relevant to electrophysiologists, Sunderland grading system is mostly used by surgeons and helps them by deciding when and how to intervene as illustrated in the Table 1 below [12].

Table 1 :- Sunderland Grading of peripheral nerve injuries.

	Degree of nerve injury	Myelin	Axon	Endo-neurium	Peri-neurium	Epi neurium	Tinel sign	MRN (signal intensity)	Recovery potential	Rate of recovery	Surgery
I	Neurapraxia	±					No	Nerve-increased T2 SI Muscle-Normal	Full	Upto 12 weeks	None
II	Axonotmesis	Yes	Yes	No	No	No	Yes	Nerve-increased T2SI and diffusely enlarged	Full	1mm/day	None
III		Yes	Yes	Yes	No	No	Yes	Fascicles enlarged or effaced due to edema Muscles- denervation	Usually slow incomplete	1mm/day	None or Neurolysis
IV	NIC-neuroma in continuity	Yes	Yes	Yes	Yes	No	Yes but no advancement	Nerve focally enlarged with heterogeneous SI. Underlying diffuse abnormality ± Fascicles disrupted with heterogeneous SI NIC Muscles-denervation	Poor to none	Poor to none	Nerve repair, graft or transfer
V	Neurotmesis	Yes	Yes	Yes	Yes	Yes	Yes but no Advancement	Complete nerve discontinuity ± haemorrhage and fibrosis in the nerve gap and end-bulb neuroma proximally. Epineural thickening Muscles-Denervation	None	None	Nerve repair, graft or transfer
VI	Mixed injury (I to V)	Variable combination of above across the cross section of the nerve					Some fascicles (II), (III)	Variable findings along the circumferential segment of the nerve (I-V) with heterogeneous SI due to fibrosis. Muscles-denervation	Variable, can be poor to none	Variable, depends upon the injury (I-V)	Neurolysis, Nerve repair, graft or transfer

MRN: Magnetic resonance neurography, SI. Signal intensity

We have emphasized more on the Sunderland grading system in our study as it is more relevant from management and surgical point of view.

Early and correct diagnosis of peripheral nerve disorders is important to guide accurate patient management. Assessment of peripheral nerve pathologies, including traumatic nerve injury and its post-operative outcome was conventionally dependent on clinical examination and electrodiagnostic studies i.e. Nerve conduction velocity (NCV) and Electromyography (EMG) studies [13,14].

Clinical examination and electrodiagnostic studies do not provide complete details regarding the anatomy and grading of nerve injuries. These studies are poor in differentiating Sunderland grade III,IV and V injuries, which is important from surgical management and prognosis point of view[8,10]. Most of the patients having low grade nerve injury undergo conservative management. The risk versus benefit should be weighed in deciding about the conservative management because an unfortunate event of poor regeneration response of the nerve will lead to atrophy of the regional muscles and no other option will be left than complex surgical treatment methods such as tendon transfers. Moreover, there will be permanent disability with consequent poor quality of life.

The leading mechanism of recovery of nerves after traumatic injuries is proximodistal axonal regeneration. However, it is a slow process (~1mm/day), and it can be assessed clinically only by the “advancing Tinel’s sign” which is often not reliable, subjective, and frequently inaccurate. The electrodiagnostic studies are also not satisfactory as they are completely dependent on target innervation and due to poor interobserver reliability.

Therefore, it is important for development of a technique that is able to evaluate the continuity of the nerve and can be used in follow up of the injured nerve to assess the regeneration of the injured axons. Also the non-traumatic peripheral nerve pathologies are needed to be evaluated in a more precise and objective manner.

Ultrasound and MRN are the main radiological modalities for evaluation of peripheral nerves[15,16]. However, Ultrasound shows limited reproducibility compared to MRN, because it is operator dependent and requires expertise to diagnose peripheral nerve injury accurately[17].

High field (3 Tesla) imaging using high resolution MRN techniques is an important non-invasive modality that can both diagnose as well as help in grading of nerve injuries, ultimately assisting in diagnostic and therapeutic workup of patients having peripheral nerve pathologies. Whole path of almost any peripheral nerve can be evaluated in a much more reproducible manner using MRN as compared to Ultrasound. Also, MRN is better for assessment of deep or difficult areas such as the lumbar plexus[18], and other tissues such as bones and muscles can be evaluated in the same study and can show ancillary imaging features like denervation oedema[19]. 3D Fat Sat and Diffusion images are also very useful for surgical planning. MRN is also a useful tool in assessing post-surgical outcomes and complications [10,20,21].

The table below depicts interpretation of MRN findings in peripheral nerve pathologies:-

Table 2 :- MRN Interpretation of Peripheral Nerves

Feature	Normal Nerve	Abnormal Nerve
Size	Similar to adjacent arteries, and gradual decreases distally	Focal or diffuse enlargement, larger than adjacent arteries
Signal Intensity	Isointense to skeletal muscle on T1 &T2W images; Isointense to slightly hyperintense on STIR and T2 Fat Sat images	Hyperintense on T2W images similar to adjacent veins
Fascicular pattern	Preserved both on T1 &T2W images	Enlargement or disruption of fascicles
Course	Smooth & outlined by perineural fat	Local or diffuse deviations, discontinuity
Enhancement	Absent (except in damaged blood nerve barrier e.g. dorsal nerve root ganglion)	Present (in tumours & infections)
Perineural fat planes	Clean and preserved	Obscured

MRN has been successfully used to confirm clinical suspicion of peripheral neuropathy by directly showing the nerve abnormality or regional muscle denervation changes; to assess the extent of the abnormality in nerve injuries or the disease load in diffuse peripheral nerve lesions, such as hereditary neuropathies and neurofibromatosis; to depict the lesions causing nerve entrapment or impingement; to exclude the diagnosis of neuropathy by showing normal nerves and regional muscles; and to detect incidental lesions in the region of interest that mimic neuropathy symptoms.

This thesis aims to comprehensively review the current state of MRI neurography, including its technical principles, clinical applications, and future directions. By synthesizing existing literature and incorporating recent advancements, this thesis seeks to provide a holistic

understanding of MRI neurography's role in the diagnosis and management of peripheral nerve disorders.

The spectrum of various peripheral nerve pathologies will be discussed, and findings of MRN will be correlated with that of NCV studies and histopathological examination correlation (wherever possible).

AIMS AND OBJECTIVES OF THE STUDY

1. To evaluate the spectrum of focal peripheral nerve pathologies on MR Neurography.
2. To correlate the MR Neurography abnormalities with Nerve Conduction Velocity studies and/or Electromyography findings.
3. To correlate the MR Neurography abnormalities with Surgical and/or Histopathological findings wherever possible.

REVIEW OF LITERATURE

Peripheral nerve pathologies encompass a range of conditions that can result in significant morbidity if not accurately diagnosed and managed. The advent of 3 Tesla (3T) MRI neurography has marked a substantial improvement in the imaging of these conditions, offering enhanced resolution and better diagnostic capabilities. This review aims to summarize the current literature on the utility of 3T MRI neurography in the evaluation and management of peripheral nerve pathologies.

Advancements in MRI Technology

High-Field Strength MRI

3T MRI provides a higher signal-to-noise ratio compared to 1.5T MRI, which translates into superior image quality. The increased field strength enhances spatial resolution, allowing for more precise visualization of nerve anatomy and pathology.

- **Thawait S.K et al. (2011)** [22] highlighted that 3T MRI significantly improves the depiction of peripheral nerves and associated pathologies due to its higher resolution and contrast capabilities as compared to conventional STIR images acquired on 1.5 T scanners.

Technical Improvements

The application of specialized imaging sequences such as Diffusion Tensor Imaging (DTI) and nerve-specific protocols has further improved the ability of 3T MRI to visualize peripheral nerves.

- **Chhabra et al. (2011)** [23] discussed the utility of advanced imaging techniques in more powerful 3T MRI scanners, emphasizing their role in enhancing diagnostic accuracy in peripheral nerve pathologies. They highlighted higher signal to noise ratio, better spatial resolution and homogeneous fat suppression in 3T as compared to 1.5T MRI. The acquisition time also reduces significantly while using 3T MRI.

Clinical Applications

Tumors and Mass Lesions

3T MRI is particularly useful in evaluating nerve sheath tumors, such as schwannomas and neurofibromas. The high-resolution images facilitate accurate assessment of tumor size, extent, and relationship to adjacent structures.

- **Chhabra et al. (2013)** [24] emphasized the value of 3T MRI and DTI in the diagnosis and characterization of peripheral nerve tumors and masses, noting its role in improving surgical outcomes .

Diagnosis of Peripheral Nerve Injuries

3T MRI neurography is highly effective in diagnosing traumatic nerve injuries, entrapment neuropathies, peripheral nerve and nerve sheath tumors and plexopathies. It provides detailed anatomical information crucial for surgical planning and intervention.

- **Fisher et al. (2016)** [25] demonstrated that MRN is very helpful in detecting and characterizing suspected brachial plexopathies, offering critical insights for surgical management.
- **Vaishali et al. (2016)**[26] also concluded a good correlation between MRN diagnosis and intra op findings in their study subjects presenting with traumatic brachial plexus injuries.

Evaluation of Neuropathies

In conditions such as diabetic neuropathy, entrapment neuropathies, and inflammatory neuropathies, 3T MR Neurography helps in identifying the extent and pattern of nerve involvement.

- **Mostafa et al. (2016)**[27] conducted a cross sectional study and observed a good diagnostic accuracy of MRN in diagnosis of nerve entrapment disorders in upper limbs with good depiction of the nerve anatomy and signal abnormalities.

3T MRI vs. Other Imaging Modalities

Compared to ultrasound and conventional radiography, 3T MRI provides superior soft tissue contrast and spatial resolution.

- **Nischal et al (2021)**[28] found a higher overall diagnostic accuracy (89.3%) of MRN as compared to that of HRUS (82.9%).
- **Parvathy et al. (2023)** [29] compared the usefulness of High resolution Ultrasound(HRUS) and MRN in evaluating peripheral nerve pathologies. They emphasized that MRN has a higher sensitivity and specificity to detect peripheral neuropathy due to its higher soft tissue contrast and ability to detect T2 signal abnormalities. On the other hand, the accuracy of HRUS is poor in evaluation of deeply located nerves and in presence of calcification. Moreover HRUS accuracy is dependant on the radiologist's skill and experience, however it has higher spatial resolution and provides real time imaging.

Comparative Studies

3T vs. 1.5T MRI

Studies comparing 3T MRI with 1.5T MRI consistently show that the former provides better image quality, lesion characterization, and diagnostic confidence.

- **Jung et al. (2023)**[30] highlighted that 3T MRN is often preferable due to increase in signal to noise ratio which indirectly leads to enhanced temporal, spatial as well as contrast resolution as opposed to 1.5 T MRI. However 1.5 T is beneficial in the case of metallic prosthetic grafts.

Limitations and Challenges

Artifacts and Image Distortion

High-field MRI, including 3T, can be prone to motion artifacts and image distortion, particularly near metallic implants or dense bone structures.

- **Filler et al. (2009)** [4] discussed these challenges and the importance of using advanced imaging techniques to minimize artifacts and improve image quality.
- **Kollmer et al. (2021)** [31] highlighted the common pitfalls in interpretation of MRN including aberrant focal T2 hyperintense

signal at physiologic sites of constrictions as well as the artifact due to magic angle effect and the ways to tackle these problems.

Cost and Accessibility

The cost and limited availability of 3T MRI can be significant barriers, especially in low-resource settings. The high cost of equipment and maintenance, along with the need for specialized training, restricts its widespread use.

Conclusion

3T MRI neurography represents a significant advancement in the imaging of peripheral nerve pathologies, offering detailed anatomical and pathological information crucial for diagnosis and management. Despite its limitations, the benefits of high-resolution imaging and improved diagnostic accuracy make it a valuable tool in clinical practice. Future research and technological developments will likely further enhance its utility and accessibility.

MATERIALS AND METHODS

The study was conducted over a period of one and a half years starting from 15 September 2022 to 8 March 2024 on patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the department of Radiodiagnosis and Imaging, Dayanand Medical College and Hospital, Ludhiana.

SOURCE OF DATA

A prospective study was done over a period of one and a half year starting from 15 September 2022 to 8 March 2024 on patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the Department of Radiodiagnosis and Imaging at Dayanand Medical College and Hospital, Ludhiana.

METHOD OF COLLECTION OF DATA

Inclusion Criteria

All patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to Dayanand Medical College and Hospital, Ludhiana.

Exclusion Criteria

1. Patients not willing for the study
2. Patients who have already been operated for some peripheral nerve disorder.
3. Patients having metallic foreign body implants.
4. Patients having implanted cardiac pacemaker, or insulin pumps, or gastric reflux device.

MR imaging technique

The subjects were examined on MAGNETOM SKYRA 48 Channel 3 Tesla MRI Scanner by Siemens, Germany after taking informed consent in his/her vernacular language before making him/her part of the study and relevant history was elicited from each patient. The following MRI sequences were taken of the area of interest/injury and were analysed:

Table 3 :- MRI Acquisition Parameters

Sequence	T1 TSE Transverse	T2 TSE Transverse	PD-FS TSE Transverse	3D T2 SPACE STIR COR	3D DWI Transverse	T2 3D DIXON	COR STIR
Acquisition time	03:40 min	03:50 min	03:10 min	03:54 min	02:20 min	06:00 min	03:46 min
Orientation	Transv Erse	Transv erse	Transv erse	Coronal	Transv erse	Coronal	Coronal
Resolution Matrix	320* 100	448* 81	320* 80	384* 60	128* 91	256* 65	384* 75
No. of slices	30	30	30	96/slab	30	160/slab	80/slab
FoV Read (mm)	170	170	170	380	260	150	330

FoV Phase (%)	100	100	100	60.4	68.8	100	59.4
Slice Thickness (mm)	3	3	3	1.5	3	0.6	1.5
Slice Gap (mm)	1	1	1	1	1	1	1
Repetition Time (msec)	920	5000	4710	3000	8060	14.1	5160
TE (msec)	21	71	24	283	57	5	61
Flip Angle	147	140	150	—	—	25	160
Flow Compression	No	No	Read	No	—	No	Read

ELECTRODIAGNOSTIC STUDIES INTERPRETATION:

The electrodiagnostic studies were used as the gold standard in this study for evaluating diagnostic accuracy of MRN in focal peripheral nerve pathologies. All the subjects underwent electrodiagnostic studies (NCV &/or EMG) and the findings were simplified as normal or abnormal for the comparison purposes. Surgical/histopathological findings were obtained wherever possible.

MRN diagnosis were also simpilified as normal or abnormal in all the subjects and were compared with electrodiagnostic studies and/or surgical/histopathological findings wherever possible for statistical analysis.

DURATION OF STUDY- 1.5 years starting from 15 September 2022 to 8 March 2024.

STATISTICAL ANALYSIS

Data were described in terms of frequencies (number of cases) and relative frequencies (percentages) as appropriate. For comparing categorical data, Chi square ($\chi 2$) test was performed and exact test was used when the expected frequency is less than 5. Sensitivity, specificity, positive and negative predictive values and accuracy of each method and its confidence interval (95% CI) were also determined. A probability value (*p* value) less than 0.05 was considered statistically significant. All statistical calculations were done using (Statistical Package for the Social Science) SPSS 21.0 version (SPSS Inc., Chicago, IL, USA) statistical program for Microsoft Windows.

OUTCOME:

To analyze the role of MR Neurography in clinical management of patients with focal peripheral nerve pathologies.

OBSERVATIONS AND RESULTS

Demographic Data

The study was conducted on 58 patients over a period of one and a half year starting from 15 September 2022 to 8 March 2024.

All the patients had a clinical diagnosis of focal peripheral nerve pathology and were referred for MRN examination. All the patients underwent Nerve Conduction Velocity/ Electromyographic study which was taken as the reference standard for the diagnosis. The age range of the patients was 6 months to 79 years, including 37 males and 21 females as demonstrated in Table 4 and figure 1.

Table 4 :- Age and Gender Distribution

AGE GROUP (YEARS)	SEX				Total
	FEMALES		MALES		
< 10	3	14.3%	1	2.7%	4
11-20.0	1	4.8%	7	18.9%	8
21-30	5	23.8%	8	21.6%	13
31-40	5	23.8%	7	18.9%	12
41-50	5	23.8%	10	27.0%	15
51-60	1	4.8%	4	10.8%	5
> 60	1	4.8%	0	0.0%	1
Total	21	100.0%	37	100.0%	58

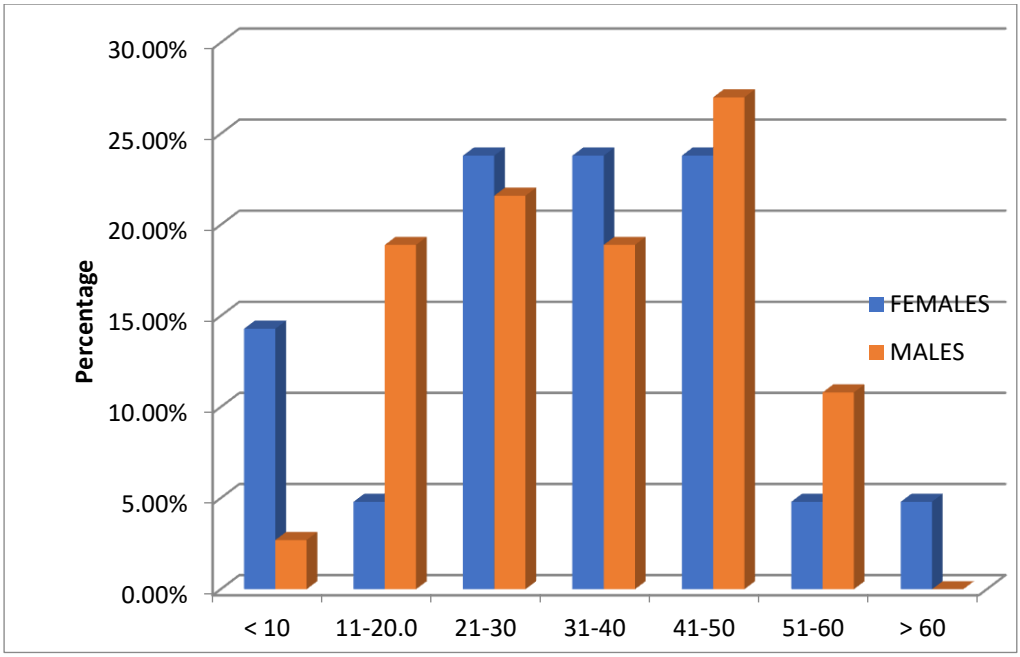

Figure 1:- Age and gender distribution of patients.

Pattern of clinical presentation

The patients presented with clinical symptoms and signs of peripheral nerve pathologies including local motor weakness (both traumatic and non-traumatic), atrophy, as well as sensory symptoms such as localised pain, numbness, pin and prick sensation and even partial or complete loss of sensations. We broadly classified the patients on the basis of presence or absence of motor and sensory symptoms for simplification.

13 patients had only sensory symptoms, while 9 patients presented only with motor weakness. Rest of the patients (36) were having mixed motor and sensory loss in the region of affected peripheral nerve or plexus.

Table 5 :- Distribution of Motor Weakness

Motor Weakness	No. of cases	Percentage
Absent	13	22.4%
Present	45	77.6%
Total	**58**	**100.0%**

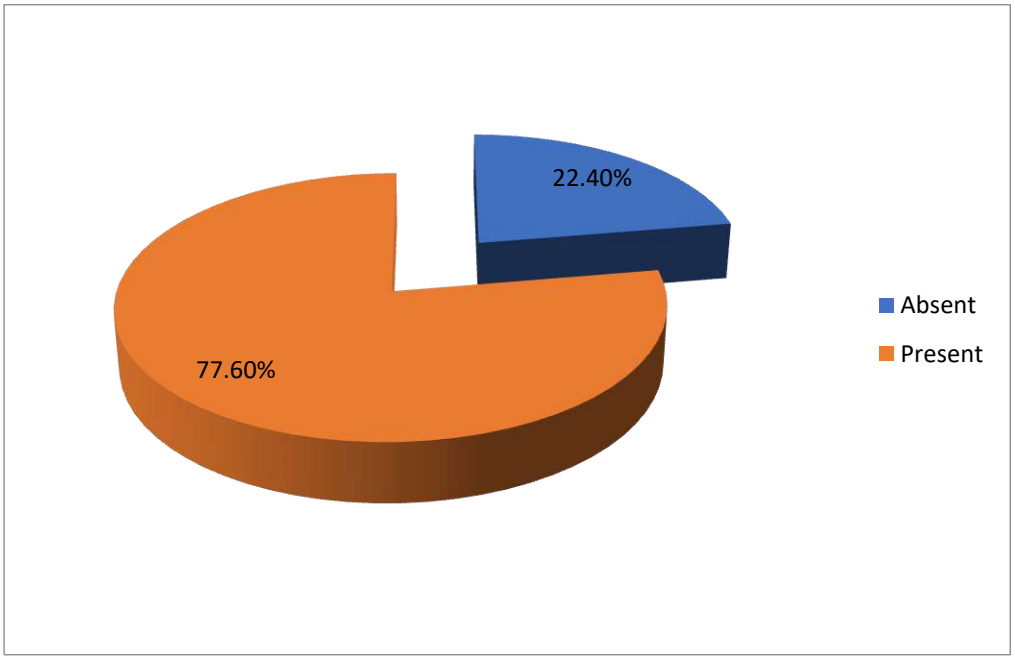

Figure 2 :- Distribution of motor weakness

Table 6:- Distribution of Sensory Symptoms

Sensory Symptoms	No. of cases	Percentage
Absent	9	15.5%
Present	49	84.5%
Total	**58**	**100.0%**

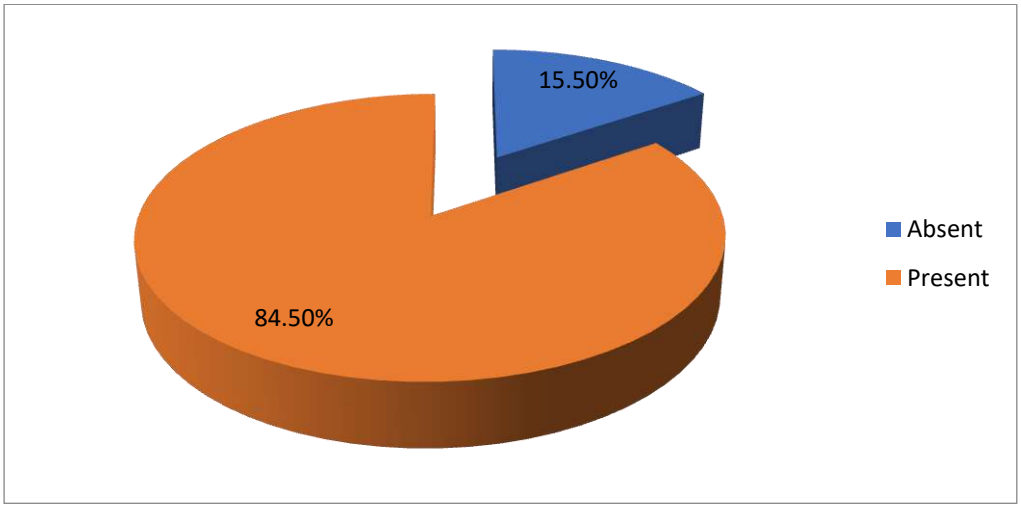

Figure 3:- Distribution of sensory symptoms

Table 7:- Distribution of motor and sensory symptoms

	No. of cases	**Percentage(%)**
Only Motor Symptoms	9	15.5 %
Only Sensory Symptoms	13	22.5%
Mixed Motor & Sensory Involvement	36	62%
Total	**58**	**100%**

MRN Diagnosis

Out of all the patients who were examined using MRN, 52 patients (89.6%) were found to have abnormal results, whereas in 6 patients (10.3%), no significant abnormality was observed (Table 8 and figure 4).

TABLE 8 :- Distribution of MRN Diagnosis

MRN Diagnosis	No. of patients	Percentage
Abnormal	52	89.7%
Normal	6	10.3%
Total	58	100.0%

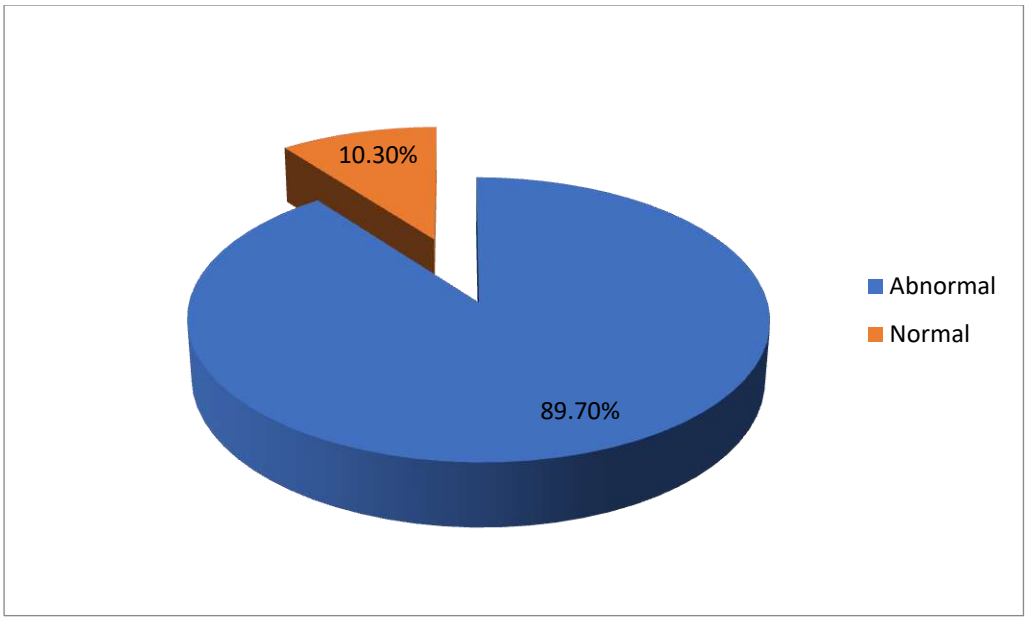

Figure 4:- Distribution of MRN Diagnosis

The spectrum of various peripheral nerve pathologies diagnosed on MRN include 34 traumatic injuries ranging from Grade I to Grade V Sunderland injury.

In 12 patients, compression/impingement disorders were diagnosed.
4 patients were diagnosed with neoplasms (one lipoma, one metastatic soft tissue infiltration and two neurogenic tumors).
Infectious pathologies were diagnosed in only 2 patients which include leprosy.
6 patients were diagnosed with demyelinating/inflammatory peripheral nerve pathologies.
In 6 patients no significant abnormality was observed on MRN.

TABLE 9:- Spectrum of peripheral nerve pathologies diagnosed on MRN

Peripheral Nerve Pathologies	No. of patients	Percentage (%)
Traumatic injuries	28	48.3
Tumours	4	6.8
Compression/ Impingement	12	20.6
Infectious	2	3.5
Demyelinating/Inflammatory	6	10.4
Normal	6	10.4
TOTAL	58	100

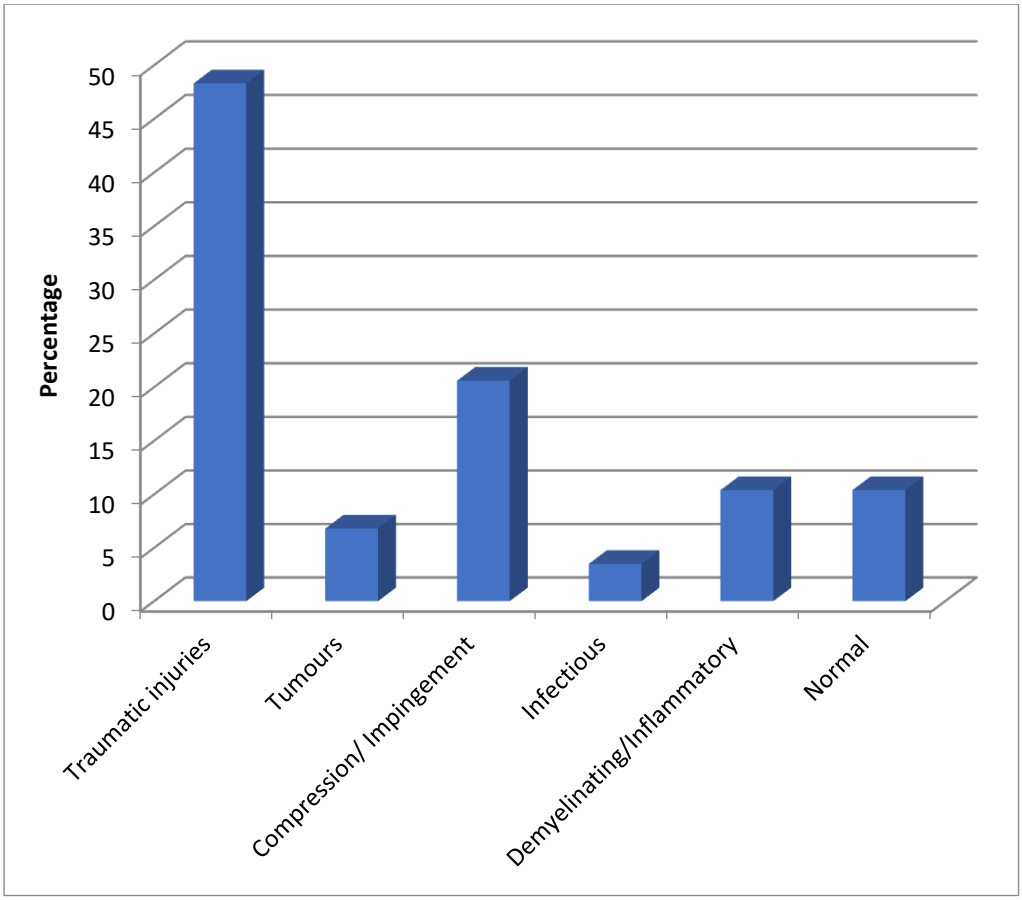

Figure 5:- Spectrum of peripheral nerve pathologies diagnosed by MRN

`The table 10 and figure 6 below show distribution of nerve impingement/compressive pathologies diagnosed on MRN. 12 patients were found to have compression/impingement of the peripheral nerves which included carpal tunnel syndrome(1), cubital tunnel syndrome(1), impingement of the nerve roots by herniated discs(3), arcade of frohse syndrome(1), entrapment of sciatic nerve by fibrotic soft tissue(1), compression of brachial plexus divisions/cords by cervical ribs or posteriorly retracted clavicle impinging upon divisions of brachial plexus(3), compression of posterior interosseous nerve in forearm by lipoma(1), compression of ulnar nerve by accessory anconeus epitrochlearis muscle(1) etc.

Table 10:- Nerve impingement/compression disorders diagnosed on MRN.

Etiology of compression/impingement	**No. of patients**
Carpal tunnel syndrome	1
Cubital tunnel syndrome	1
Impingement of ulnar nerve by arcade of frohse	1
Entrapment of sciatic nerve by fibrotic soft tissue	1
Compression of brachial plexus divisions/cords by cervical ribs or posteriorly retracted clavicle	3
Compression of posterior interosseous nerve by lipoma	1
Compression of ulnar nerve by accessory anconeus epitrochlearis muscle	1
Impingement of nerve roots by herniated discs	3
Total	**12**

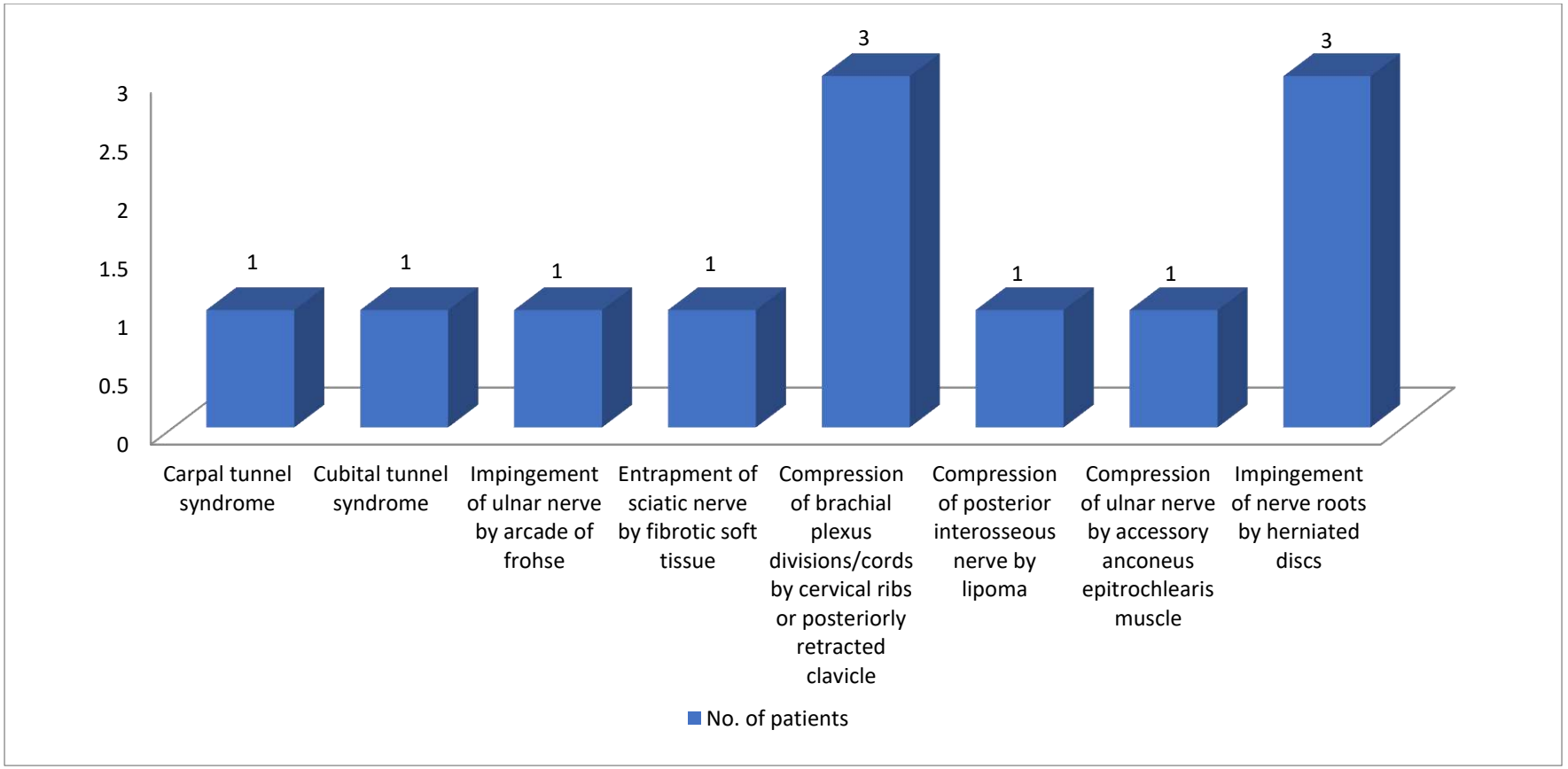

Figure 6:- Spectrum of nerve impingement/compression disorders diagnosed by MRN

Among the patients diagnosed with traumatic peripheral nerve injury (28), 5 were found to have grade I injury, 4 with grade II, 6 with grade III, 4 with grade IV and 9 patients with grade V injuries respectively being demonstrated in Table 11 and figure 7.

Table 11:- Distribution of traumatic peripheral nerve injuries.

Sunderland Grade	No. of patients	Percentage(%)
Grade I	5	17.8
Grade II	4	14.3
Grade III	6	21.4
Grade IV	4	14.3
Grade V	9	32.2
TOTAL	28	100

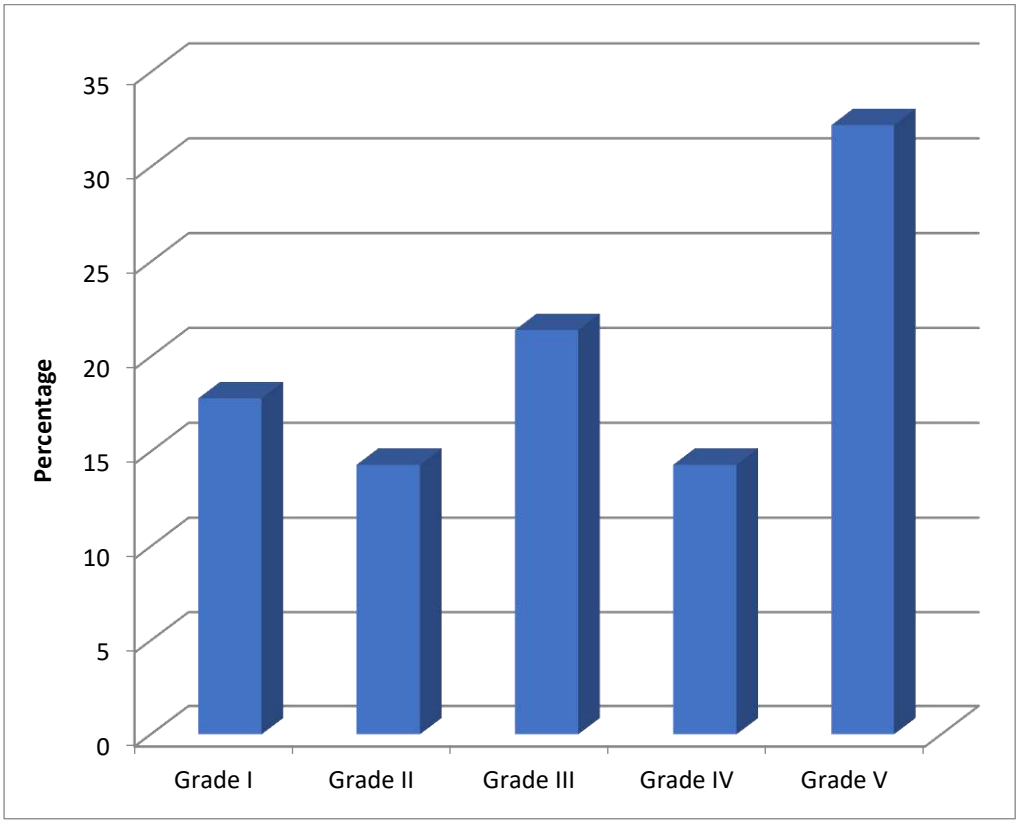

Figure 7:- Distribution of traumatic peripheral nerve pathologies

Out of all the 58 MRN examinations, 23 scans were of brachial plexus, in which as demonstrated in Table 12 and figure 8, we found 4 preganglionic injuries, 4 postganglionic injuries and 4 patients with mixed pre and post ganglionic injuries.

3 patients were diagnosed with inflammatory/demyelinating pathologies (including parsonage turner syndrome), 2 patients with infectious / parainfectious neuritis and 4 patients with compression/impingement pathologies.

Two patients were diagnosed with neoplastic etiology, with one of them having metastatic soft tissue infiltration of the brachial plexus and the other one having plexiform neurofibroma involving C5-6 nerve roots.

No significant abnormality was demonstrated in 2 patients.

Table 12 :- Distribution of pathologies diagnosed on MRN brachial plexus

Spectrum of pathologies diagnosed on MRN Brachial plexus		**No. of patients**	**Percentage (%)**
Purely preganglionic injuries		4	16
Purely postganglionic injuries		4	16
Mixed pre and postganglionic injuries		4	16
Inflammatory/demyelinating disorder		3	12
Tumors	Soft tissue infiltration of the brachial plexus	1	4
	Plexiform neurofibroma of C5-6 Nerve roots	1	4
Impingement/Compressive disorders		4	16
Infectious/parainfectious neuritis		2	8
Normal		2	8
Total		25	100

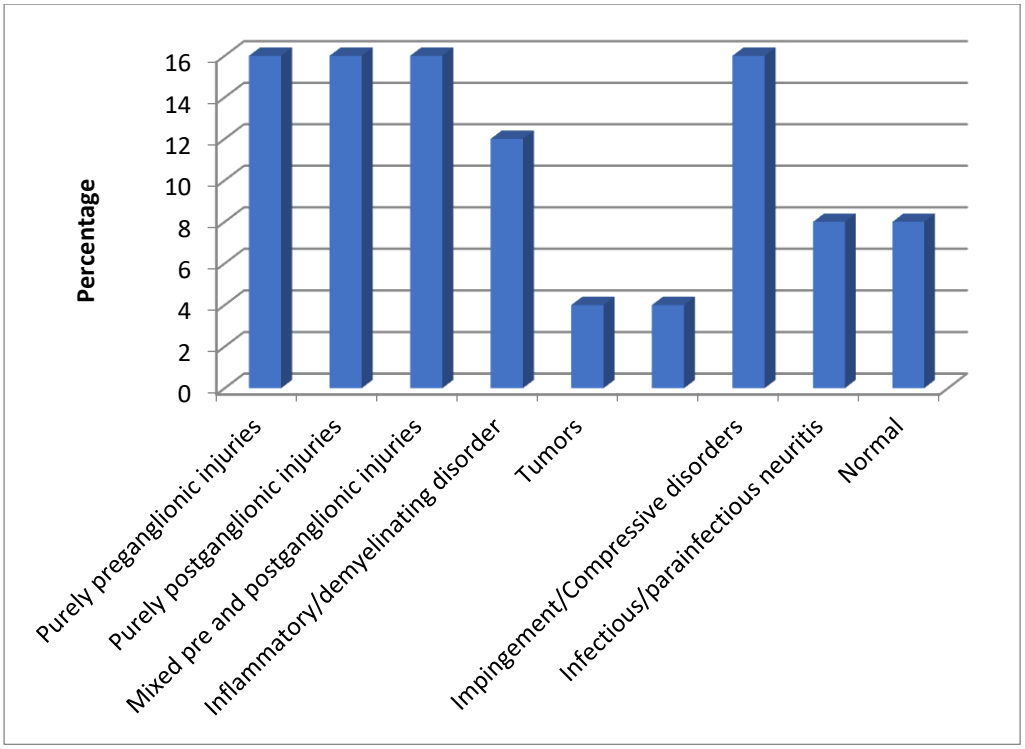

Figure 8:- Distribution of brachial plexopathies diagnosed by MRN

NCV Diagnosis

The NCV diagnosis was positive in 51 out of total 58 patients, while it was negative in 7 patients (Table 13 and figure 9).

TABLE 13:- Distribution of NCV findings

NCV diagnosis	No. of cases	Percentage (%)
Abnormal	51	87.9%
Normal	7	12.1%
Total	58	100.0%

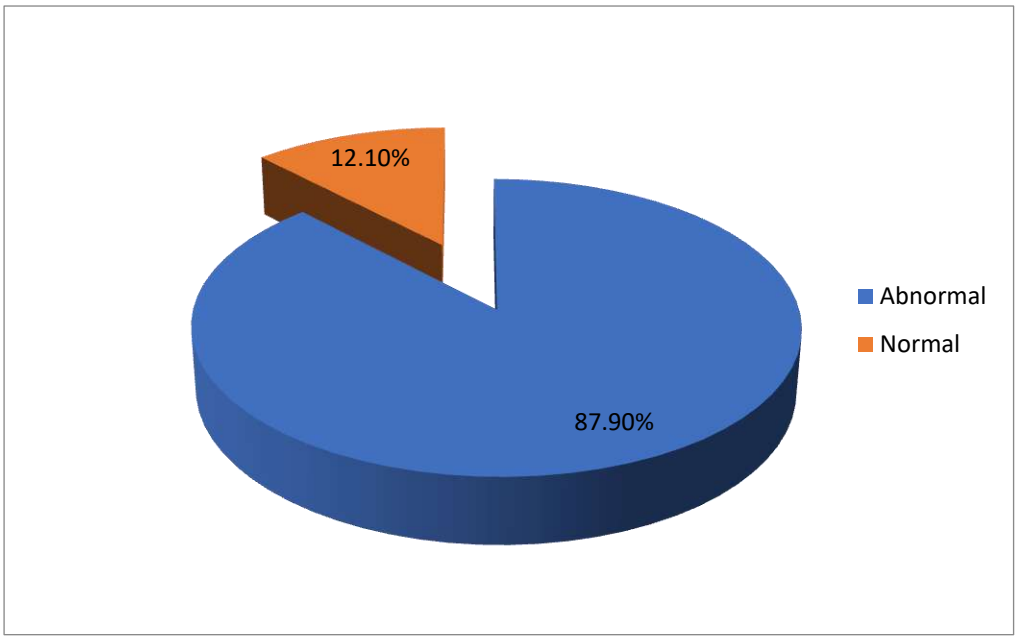

Figure 9:- Distribution of NCV findings

Correlation of MRN with NCV diagnosis

The MRN diagnosis was correlated with NCV diagnosis in all the patients and the results are demonstrated in table 14.

It was found that 6 patients had no abnormality detected on MRN, while out of these, only one patient was having an abnormal NCV result (In discordance with the MRN diagnosis) and five patients had a negative NCV – in keeping with the MRN diagnosis.

Out of the 52 patients having abnormal MRN diagnosis,50 patients were found to have abnormal NCV diagnosis as well (concordance with the MRN diagnosis), while only two patients had a normal NCV result which was in discordance with the MRN diagnosis.

Therefore, the number of True negative cases in our study was 5 out of 58 with the percentage of 8.6%, And the number of true positive cases were 50 out of 58 with the percentage of 86.3%.

However there were two false positive cases(3.4%) and one false negative case(1.7%).

Table 14:- Relationship of MRN diagnosis with NCV diagnosis

		NCV diagnosis				**Total**	**p-Value**
		Abnormal		**Normal**			
MRN diagnosis	**Abnormal**	50	98.0%	2	28.6%	52	0.03
	Normal	1	2.0%	5	71.4%	6	
Total		51	100.0%	7	100.0%	58	

The overall disease prevalence in our study was 87.93%.

The observed sensitivity of MRN in diagnosis of peripheral nerve pathologies was very good (98.04%), however with an average specificity of 71.43% (p = 0.03). The positive and negative predictive values were 96.15% and 83.33% respectively with diagnostic accuracy of 94.83%.

Table 15:- Statistical values of MRN diagnosis in overall peripheral nerve pathologies

Statistic	Value
Sensitivity	98.04%
Specificity	71.43%
Positive Likelihood Ratio	3.43
Negative Likelihood Ratio	0.03
Disease prevalence (*)	87.93%
Positive Predictive Value (*)	96.15%
Negative Predictive Value (*)	83.33%
Accuracy (*)	94.83%

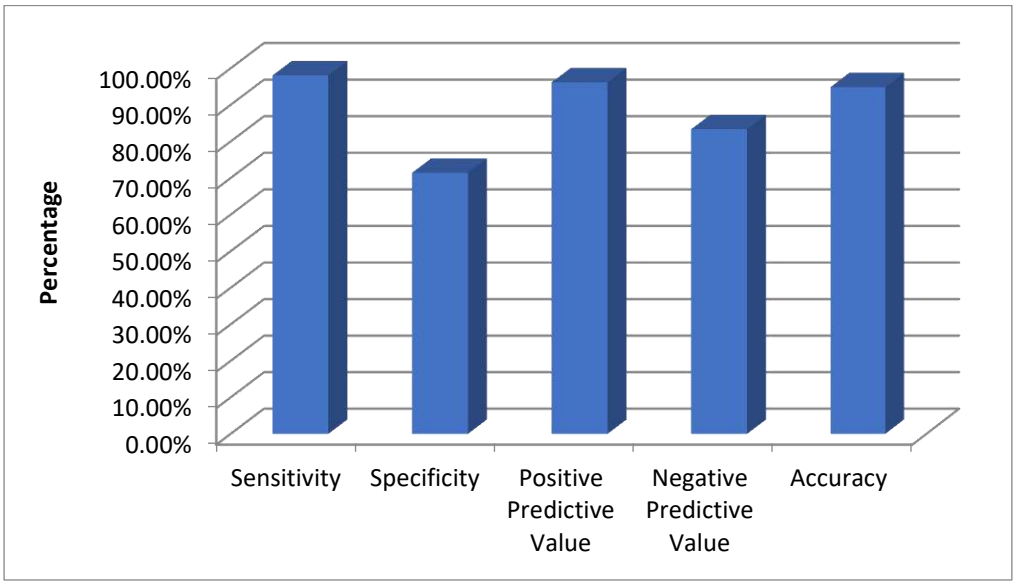

Figure 10:- Statistical values of MRN diagnosis in overall peripheral nerve pathologies

The relationship of MRN and NCV diagnosis in patients suspected for brachial plexus pathologies was calculated separately and is demonstrated in Table 16 and figure 11. There were 25 patients who underwent MRN Brachial plexus exams in this study, out of which 23 were diagnosed with peripheral nerve pathologies whereas no pathology was observed in 2 patients.

In MRN positive group (23), NCV was abnormal in 21 cases and normal in 2 cases (discordance with MRN diagnosis).

In MRN negative patients (2), one patient had positive NCV (discordance with MRN diagnosis) and one had normal NCV study.

The calculated MRN sensitivity for diagnosis of brachial plexopathies was 95.4% with a low specificity of 33.3% and a diagnostic accuracy of 88%.

Table 16:- Relationship between MRN and NCV diagnosis in patients subjected to MRN Brachial Plexus

		NCV diagnosis		**Total**
		Abnormal	**Normal**	
MRN diagnosis	**Abnormal**	21	2	23
	Normal	1	1	2
Total		22	3	25

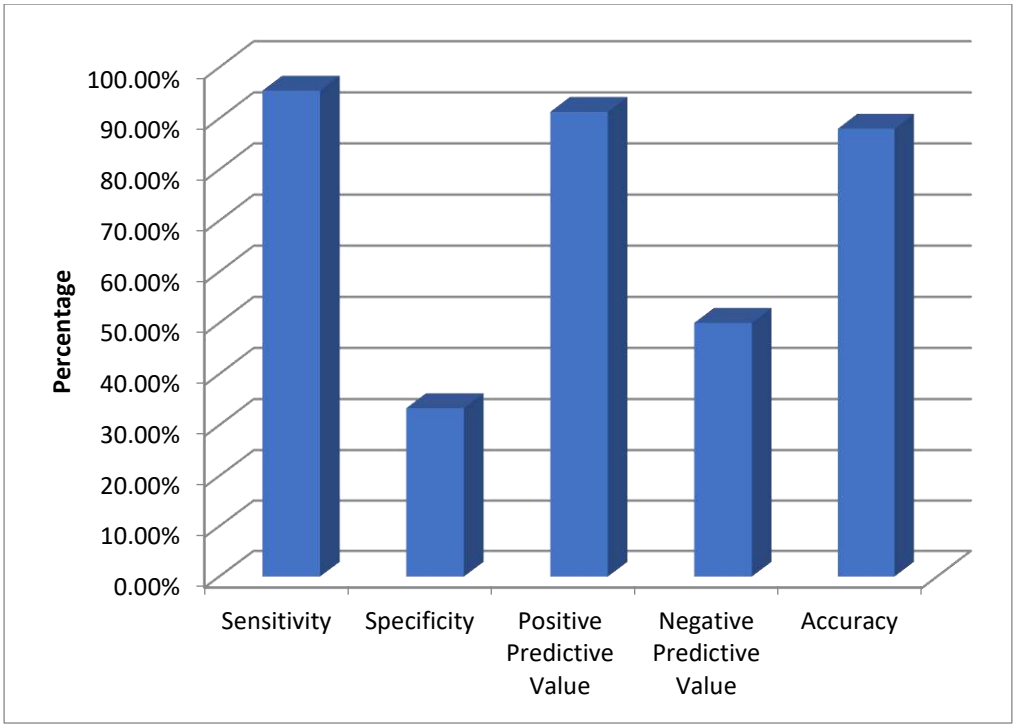

Figure 11:- Sensitivity, specificity, PPV, NPV and accuracy of MRN in diagnosis of brachial plexus pathologies

Out of total (58), only 5 patients were managed surgically and the intraoperative findings in all of them were in concordance with the MRN diagnosis.

DISCUSSION

Electrodiagnostic studies, including electromyography (EMG) and nerve conduction velocity (NCV) studies had been widely considered the standard methods for the diagnosis of peripheral nerve pathologies. History taking, clinical examination, and electrodiagnostic studies are crucial to the diagnosis and treatment of patients presenting with symptoms of peripheral nerve pathologies. Electrodiagnostic studies not only detect the presence of peripheral neuropathy, but can also give clues to the clinician regarding determination of the aetiology, the severity, and the prognosis of the disorder. These studies are indicated when a patient has sensory symptoms such as paraesthesia, pain, or motor weakness, which is unexplainable by a focal mononeuropathy, such as entrapment syndromes.

However, these studies are time-consuming to perform; may provide equivocal results, especially in post-surgical cases because of the delayed return of electrical signals; may be not comfortable to the subjects; or may even be not feasible in some patients with skin disorders and in cases of deeply situated nerves which are difficult to access [32,33]. In addition, these studies may not exactly localize the site of nerve injury and are not able to detect neuromas.

MRN and ultrasound were introduced as non-invasive modalities for imaging of the peripheral nerves in the 1980s [34–36]. Ultrasonography is useful for the evaluation of superficial nerves, relatively less expensive, and enables dynamic imaging and differentiation of nerves from blood vessels using colour doppler imaging. However ultrasound is operator-dependent and nerve imaging may be suboptimal by dense scarring and shadowing from calcifications. These issues become even more pronounced in cases of deeply situated nerves, especially in pelvis and lumbosacral plexus [37].

As compared to ultrasonography, MRN is not operator-dependent, gives higher soft-tissue resolution, and offers more detailed visualization of abnormalities of nerves and of surrounding soft tissues. Moreover, secondary denervation changes in the muscles are better demonstrated on MRN examinations.

For a long time (at least two decades), low field (upto 1.5 T) MRI scanners were used for imaging of peripheral nerves and plexus. However there were certain limitations with their usage including low imaging resolution and contrast, inconsistent fat suppression due to long acquisition times, difficulty in differentiation of peripheral nerves from blood vessels in the neurovascular bundle especially in extremities, low signal to noise and contrast to noise ratios, issues related to susceptibility artifacts etc.

Recently with the advent of high field 3T MRI scanners, new phased array surface coils, and parallel imaging have led to resolution of many of the above mentioned obstacles in imaging of peripheral nerves with reduced image acquisition times. Current state-of-the-art MRI is able to provide great anatomical details of the peripheral nerves and much better characterization of nerve pathologies[38–40]. 3D and fat saturated sequences are particularly very useful in deciding the surgical management in traumatic peripheral nerve injuries.

Although there has been evolution of MRN into a much sensitive imaging technique, its specificity for detection of peripheral nerve disorders has been repeatedly questioned [41,42]. Still there are multiple diagnostic challenges remaining, such as the interpretation of mild T2 hyperintensity of the peripheral nerves as an isolated sign of neuropathy. Mild T2 hyperintensity within the nerve can be very often observed in clinically asymptomatic individuals, that may be attributed to magic angle effect, or may represent subclinical neuropathy[41,43]. Moreover, it is often very challenging to distinguish between chronically degenerating and regenerating nerves[44]. Another pitfall of MRN is the susceptibility artefacts in the presence of metallic prosthetic implants in the extremities or elsewhere in the body.

In the past two decades, several review articles and a limited number of original scientific studies have described the application of MRN on 1.5-T and lower-field-strength scanners. Historically, compared with an electrodiagnostic study, MRN exhibited good diagnostic accuracy for nerve sheath tumours and only moderate diagnostic accuracy in the

evaluation of compressive neuropathies, such as carpal and cubital tunnel syndromes [42,45].

Recently, there has been considerable research on 3T MRN using diffusion-based imaging for nerve identification. Encouraging results have been seen with the application of DTI in animal models for the assessment of nerve regeneration and with the application of tractography in healthy human volunteers.

Distinguishing between types of traumatic nerve injuries can be difficult using clinical examination alone at initial presentation. MRN gives a fair idea of the brachial or lumbar plexus roots involved in the injury, the level and extent of involvement, the changes in the surrounding soft tissues and the presence of regenerating nerves (if any).

We therefore decided to evaluate the diagnostic accuracy of 3T MRN considering the NCV studies as the gold standard in a statistical sense and also depict the spectrum of various peripheral nerve pathologies diagnosed by MRN.

A qualitative analysis was done by simplifying the results of MRN and NCV studies in which we observed whether any abnormality was present or not in a particular nerve or plexus being imaged using MRN. Then these results were correlated with the findings of NCV studies conducted in the same area of interest or nerve being scanned in MRN. The NCV results were also simplified on the basis of whether any abnormality is present or not.

In our study, we found minimal differences between the clinical examination findings and the MRN findings, and good agreement between NCV studies and the MRN findings, with a high sensitivity (98.04%) and average specificity (71.43%).

MRN showed high positive predictive value (96.15%) and overall accuracy (94.83%) as well as negative predictive value (83.33%) in diagnosis of peripheral nerve pathologies.

In the recent past, multiple studies have compared the diagnostic accuracy of MRN with NCV studies and intra op findings especially in brachial and lumbar plexopathies as well as inflammatory / demyelinating and nerve entrapment syndromes.

An almost similar spectrum of peripheral nerve pathologies diagnosed by MRN as that of our study was seen in a retrospective study conducted by Rose Du et.al. in 2010, in which a total of 191 patients were examined using MRN[46]. MRN diagnosis was also compared with NCV/EMG results in which it was found that in the majority of cases, MRN and NCV/EMG results were in agreement, and the combined diagnostic information obtained using both these modalities was complementary.

Our results are in harmony with a former study done by Sarah Yousry et.al in 2023[47] in which the sensitivity of MR neurography in diagnosing lumbosacral radiculoplexopathies based on electrophysiological studies was 97.5% and the specificity was 75.86%, thus revealing a good agreement between MRN and electrodiagnostic studies.

Our results are also supported by a study done by Mohammed Mostafa Sayed Mostafa et.al. [27] in 2016 who conducted a cross sectional study on 40 patients who presented clinically with nerve entrapment in upper limbs. MRN showed high positive predictive value (96.4%) and specificity (83.3%), average sensitivity (79.4%) and overall diagnostic accuracy (80%), however with a low negative predictive value (41.6%) in diagnosing nerve entrapments.

A high sensitivity (94.44%) and specificity (100%) of MRN diagnosis was depicted in descriptive cross sectional study conducted by Sara Mohamed Mahmoud Mabrouk et.al. in 2021 [48] in which 40 subjects with clinical suspicion of brachial plexus abnormalities were selected for MRN examination and Electrodiagnostic studies including NCV and Electromyography. The difference in specificity could be attributed to limited spectrum in above mentioned study which was confined to brachial plexus as compared to wider spectrum of peripheral nerve pathologies and lesser number of true negative cases in our study.

A prior study done by Vaishali Upadhyaya et.al [26] in 2015 also concluded a good correlation of MRN findings with intraoperative observations in 20 subjects having traumatic brachial plexus injury. A

good correlation was observed between MRN and surgical findings in 13 out of 20 patients, average correlation in 6 patients, and poor correlation in 1 patient. On the other hand in our study, 5 patients were subjected to surgical treatment and intra operative findings in all of them were in accordance with the MRN diagnosis.

In 2022, Neehar R. Patel et. al. [49] conducted an observational cross-sectional prospective randomized study on 48 subjects with brachial plexus injuries who underwent a detailed clinical neurological examination of the upper limbs, the electrodiagnostic studies and MRN. It was observed that MRN was highly sensitive (93.88%) in detection of brachial plexus injury with a negative predictive value of 65.38%, but it lacked specificity (18.28%) with a positive predictive value of 64.49%.

In our study, a majority of cases were of brachial plexus pathologies (25), in which we found a high sensitivity (95.4%) of MRN but a low specificity (33.3%) in diagnosis of brachial plexopathies.

The sensitivity of MRN in diagnosing Brachial plexopathies in our study is comparable with the above mentioned study, however the low specificity could be attributed to small sample size of brachial plexus pathologies in our study, and relatively less number of true negative cases.

Approximately half of the brachial plexopathies diagnosed in our study composed of traumatic pre and post ganglionic injuries, with remaining spectrum consisting of impingement/compressive disorders, inflammatory/demyelinating disorders, tumors and infectious / parainfectious neuritis in decreasing order of their frequency.

MRN diagnosis rendered in our study included major segment of traumatic peripheral nerve injuries constituting 48.3% of the total cases. Other pathologies diagnosed included compression / impingement disorders, demyelinating/inflammatory pathologies, tumors and infectious etiologies. However no abnormality was detected in 6 (10.4%) of the total cases.

In the traumatic injuries major contribution was by Sunderland grade V injuries constituting 32.2% of all the traumatic peripheral nerve injuries,

followed by grade III (21.4%), grade I (17.8%), with lowest percentage of 14.3 % in grade II and IV each.

MRN is technically geared towards achieving a more uniform suppression of background fat and accompanying vessels while preserving the SNR of nerves for imaging of the plexus. With technical advancements, MRN is gaining a substantial impact on diagnostic reasoning and therapeutic treatment recommendations.

Owing to the nonconventional imaging planes and complex paths of nerves, MRN interpretation can be challenging. A clear understanding of plexus anatomy and the spectrum of abnormal findings will facilitate MRN interpretation.

This highly sensitive non-invasive imaging technique aids in early diagnosis of peripheral nerve pathologies in dicey cases, and hence timely and specific treatment for the same. Although further detailed research is needed for evaluating the utility of MRN in diagnosis of peripheral nerve pathologies.

Limitations

There were some limitations in the study which may have led to certain discrepancies of our statistical analysis as compared to some of the standard studies quoted above. These include oversimplification of the MRN diagnosis and NCV/EMG results, small and non-specific sample size and standardization of the electrodiagnostic studies for evaluating diagnostic accuracy of MRN. Another limitation is lack of intraoperative correlation in most of the cases. A study with larger sample size can further validate the accuracy of MRN.

SUMMARY AND CONCLUSION

Summary:

- Our study included 58 subjects with clinical suspicion of focal peripheral nerve pathologies who underwent MRN.
- All the patients were also evaluated by electrodiagnostic studies including NCV and EMG, however only 5 patients were managed surgically.
- The most common age group affected was between 41-50 year.
- 36 (62%) patients had both motor and sensory symptoms, while 9 (15.5%) patients had only motor symptoms and 13 (22.5%) patients had only sensory symptoms.
- The most common peripheral nerve pathologies diagnosed were traumatic injuries (48.3%) followed by compression/impingement syndromes (20.6%). Out of traumatic injuries, most common was Sunderland grade V injury.
- The sensitivity, specificity and diagnostic accuracy of MRN in diagnosis of focal peripheral nerve pathologies was 98.04%, 71.43% and 94.83% respectively.
- The sensitivity, specificity and diagnostic accuracy of MRN in diagnosis of brachial plexopathies was 95.4%, 33.3% and 88% respectively.

Conclusion:

The advancements in Magnetic Resonance Neurography [MRN], particularly with the use of 3Tesla (3T) MR scanners, have significantly enhanced the visualization of peripheral nerve pathologies. 3T MR Neurography has proven to be a valuable diagnostic tool in evaluating peripheral nerve pathologies. Its high sensitivity and good diagnostic accuracy make it superior in detecting a wide spectrum of nerve pathologies. The correlation with NCV studies and intraoperative findings further validates its clinical utility. These results suggest that 3T MR Neurography should be considered a key imaging modality in the diagnostic workflow for peripheral nerve pathologies. Future research should continue to explore its applications and potential improvements in imaging techniques.

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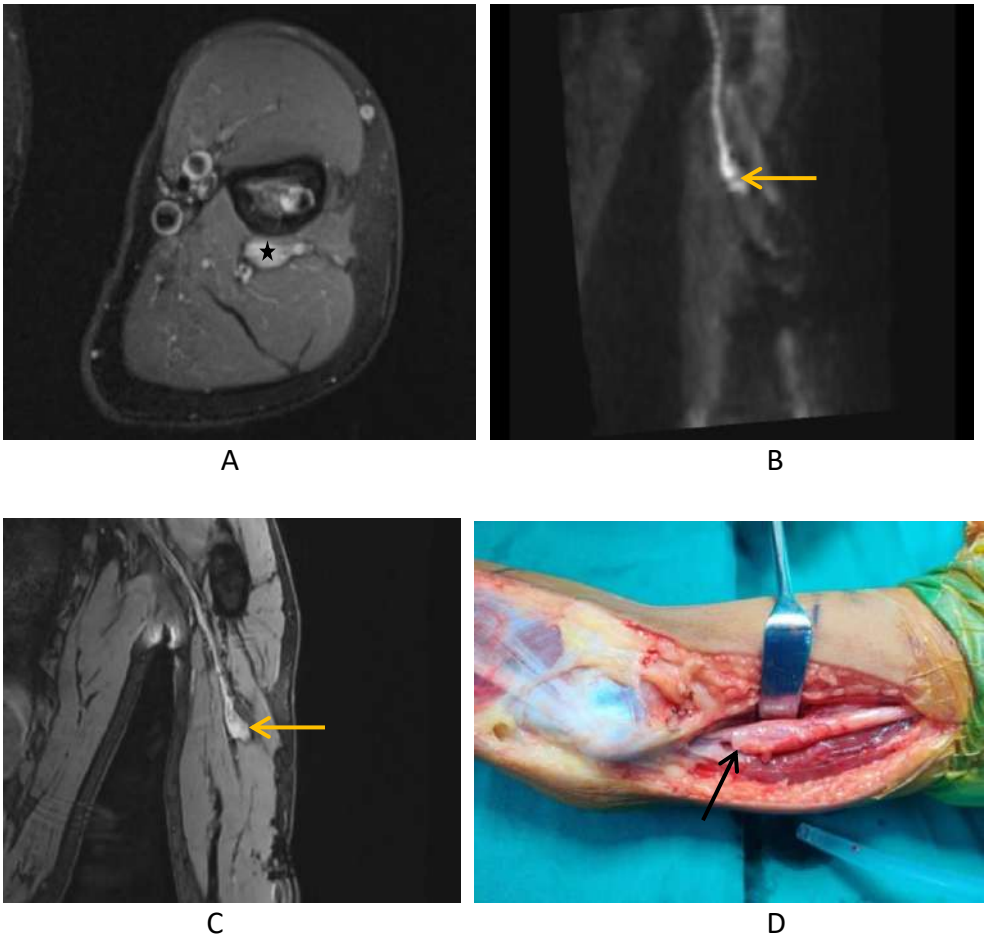
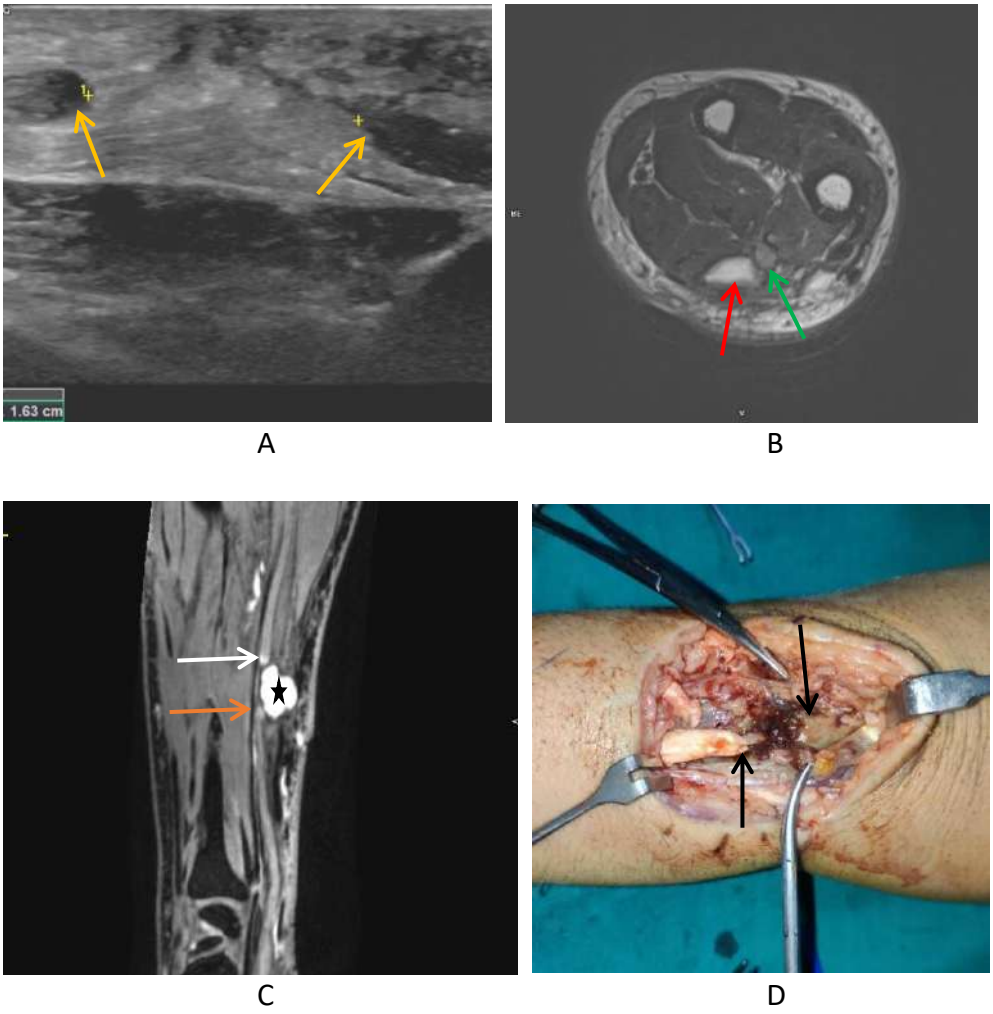


Picture 1:- A 55 year old male with occupational machine injury to left upper limb presented with weakness of extensors of forearm and hand with sensory symptoms involving extensor aspect of forearm and hand underwent MRN examination.

(A) Axial PD fat sat image shows neuroma formation involving the radial nerve at the level of radial groove (asterisk).

(B) Coronal DWI MIP and (C) 3D T2 SPACE images reveal a fusiform neuroma of the radial nerve in the radial groove (yellow arrows) with non-visualisation of the distal radial nerve – consistent with Sunderland grade V radial nerve injury.

(C) The intra operative image shows the neuroma of the transected radial nerve in the mid arm (black arrow).



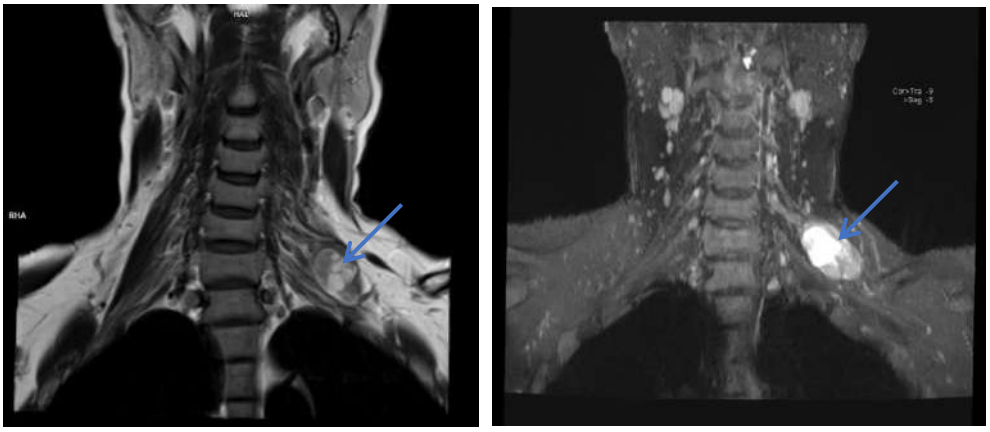
Picture 2:- A 32 year old male with glass cut injury to left forearm and clinical diagnosis of median nerve injury underwent USG and MRN examination.

(A) B mode USG image shows proximal and distal stumps (yellow arrows) of median nerve with non-visualisation of median nerve for a length of approximately 1.6 cm.

(B) Axial T2 weighted image shows neuroma formation involving the median nerve in the forearm (green arrow) with adjacent T2 hyperintense hematoma (red arrow).

(C) 3D T2 SPACE MIP image shows proximal (white arrow) and distal (orange arrow) neuromas involving median nerve in the forearm with adjacent hyperintense hematoma (asterisk).

(D) Intra operative image confirms the MRN findings with short segment non visualisation of median nerve in the distal forearm with evidence of proximal and distal neuromas (black arrows) and adjacent hematoma.



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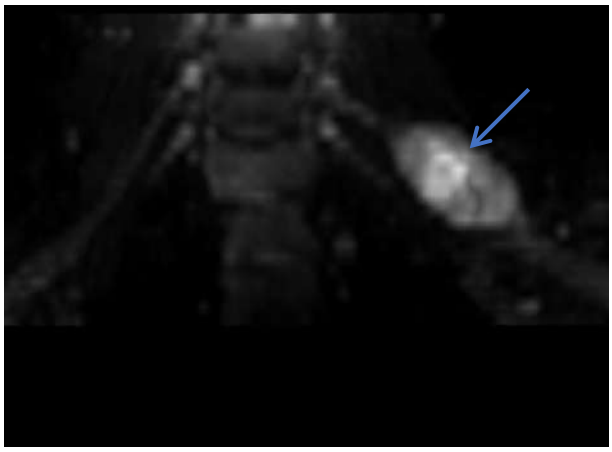

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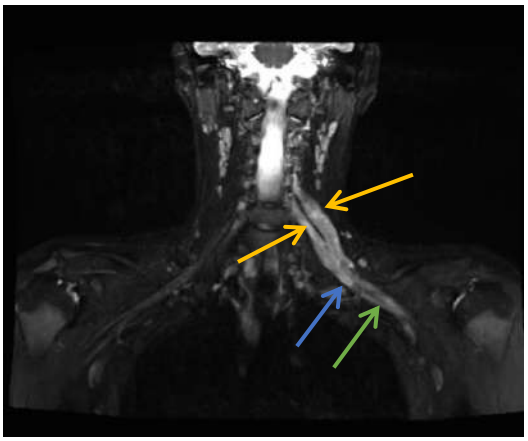
Picture 3:- Patient presenting with chronic pain and tingling sensation along lateral aspect of left shoulder and arm.
(A) Coronal T2 weighted, (B) Coronal STIR and (C) Coronal Diffusion weighted MIP images showing a well circumscribed T2 and STIR heterogeneously hyperintense lesion (blue arrows) appearing hyperintense on T2, STIR and DWI in left supraclavicular region lying inseparable from the upper trunk of left brachial plexus- suggestive of nerve sheath tumor.

A B



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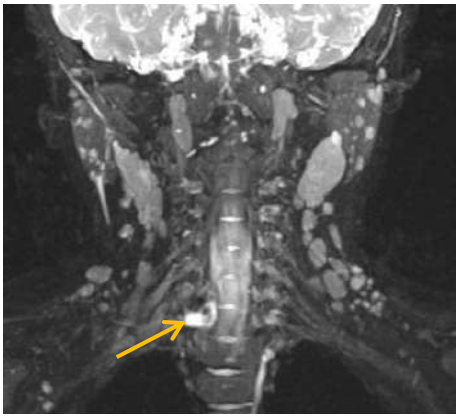
Picture 4:- A young female with clinical diagnosis of left brachial plexopathy underwent MRN examination.
(A) Coronal T2 weighted, (B) Coronal DWI MIP and (C) Coronal STIR images show diffusely thickened and hyperintense C5 and C6 nerve roots (yellow arrows), left upper trunk (blue arrows), its anterior and posterior divisions (not shown), lateral as well as posterior cords (green arrows).
It was diagnosed as a case of plexiform neurofibroma.



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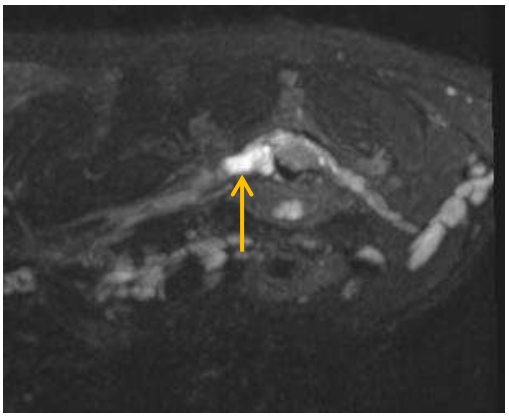

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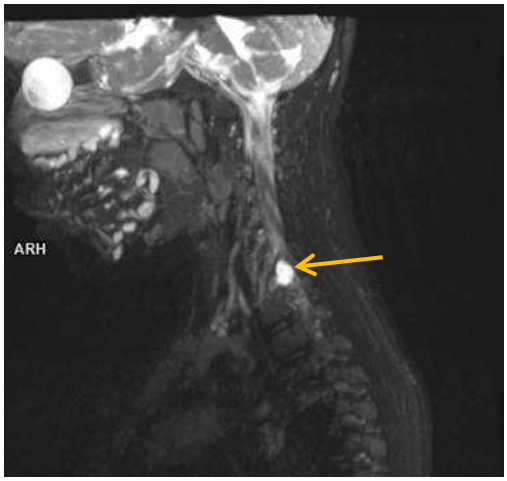

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Picture 5:- A 4 year old female with history of old brachial plexus injury underwent MRI Brachial Plexus examination.
(A) Coronal STIR, (B) Axial DWI MIP and (C) Sagittal STIR images show avulsion of anterior and posterior rootlets of C8 nerve root on right side with resultant pseudo-meningocele formation (yellow arrows)- consistent with preganglionic nerve injury involving C8 nerve root on right side.

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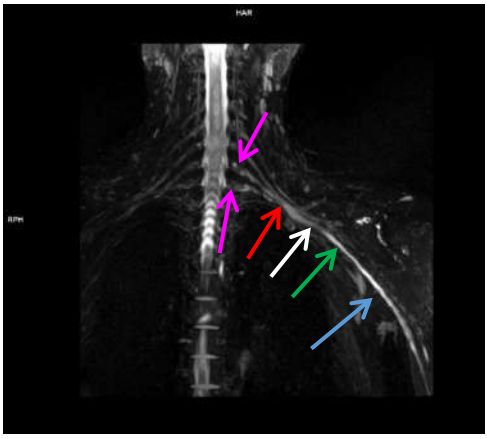

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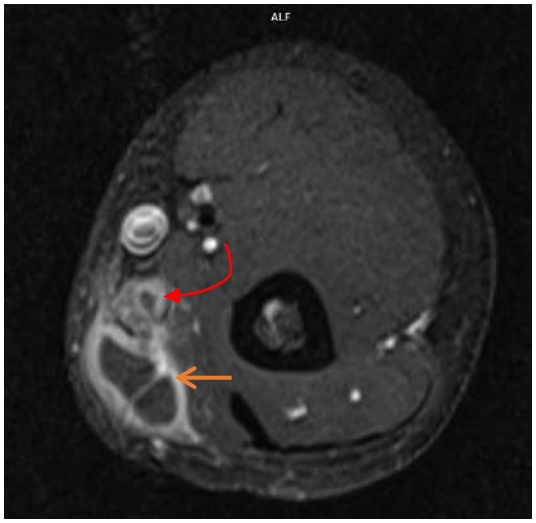

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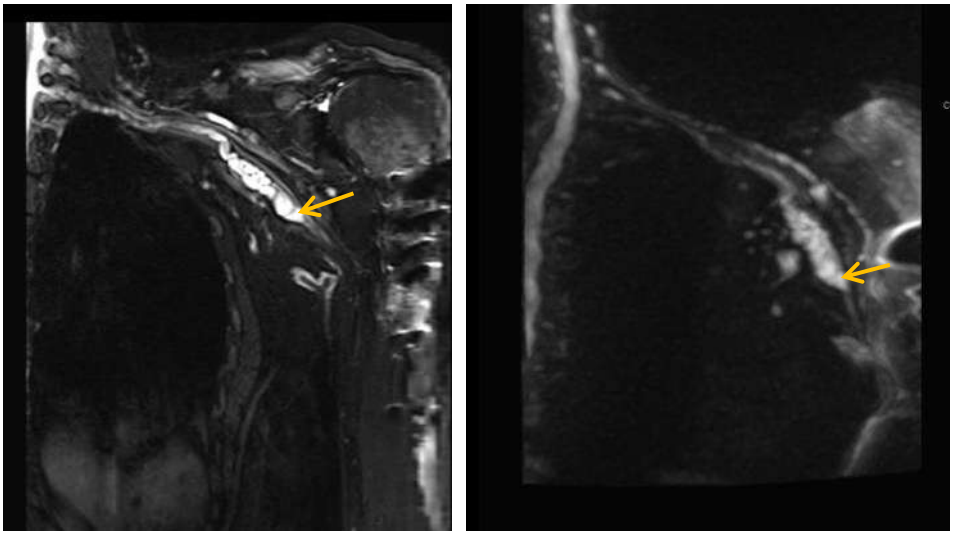
Picture 6:- (A) A 23 year old male with swelling on medial aspect of left arm (yellow arrow) and clinical features of left ulnar nerve palsy underwent MRN.

(B) 3D T2 fat sat image shows diffuse thickening and hyperintense signal involving C8 and T1 nerve roots (pink arrows), inferior trunk (red arrow), anterior cord of inferior trunk (white arrow) and medial cord (green arrow) further extending to involve the ulnar nerve (blue arrow).

(C)Coronal PD fat sat MIP image showing diffusely thickened and hyperintense ulnar nerve (curved white arrow) near the cubital tunnel with a hyperintense collection (asterisk) communicating with the ulnar nerve.

(D)Axial T1 post contrast image showing thick peripheral enhancement of the thickened nerve (curved red arrow) with adjacent peripherally enhancing collection (orange arrow).

It was confirmed on histopathological examination to be a case of leprosy.



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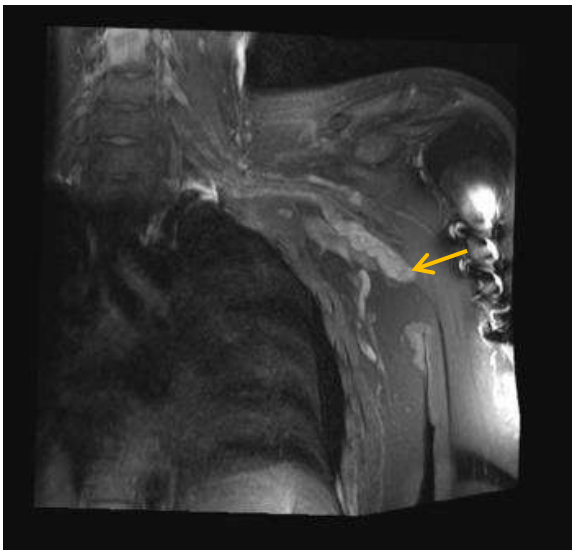

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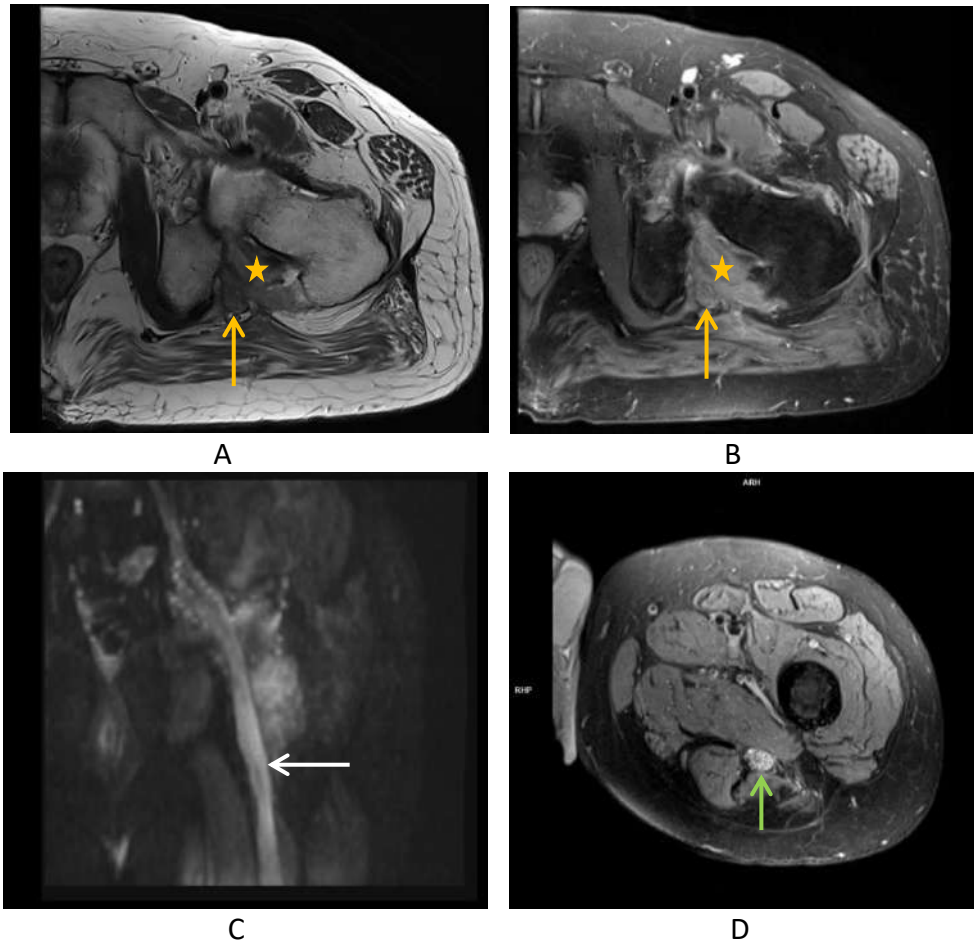
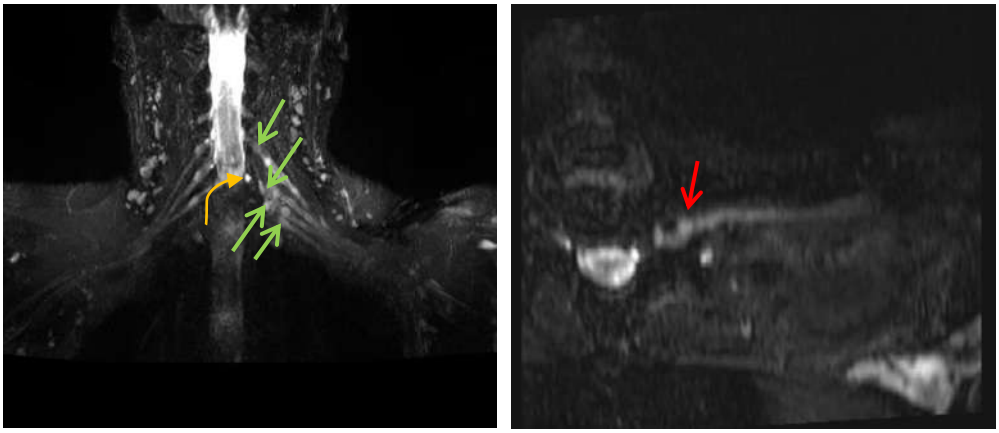
Picture 7:- A case of traumatic injury to left upper limb with weakness of flexor muscles of forearm and hand who underwent MRN for further evaluation.
(A) Coronal 3D T2 SPACE, (B) Coronal Diffusion weighted MIP and (C) Coronal PD fat sat images reveal thickened and hyperintense median nerve with retraction of proximal stump in the axilla (yellow arrows) in keeping with Sunderland grade V median nerve injury.



Picture 8:- An old case of road traffic accident with fracture of posterior column of left acetabulum presented with sciatica.
(A) Axial T2 weighted and (B) axial PD fat sat images show an ill-defined T2 intermediate signal intensity soft tissue (yellow asterisks) just posterior and inferior to the fracture site. The soft tissue is causing traction on sciatic nerve fascicles (yellow arrows) with resultant architectural distortion.
(C) Diffusion weighted MIP image shows diffusely thickened and hyperintense sciatic nerve in upper 2/3rd of thigh (white arrow).
(D) Axial PD fat sat image at the level of mid-thigh shows markedly thickened sciatic nerve (green arrow) with preserved fascicular pattern.
It was a case of at least grade III/IV sciatic nerve injury secondary to entrapment by the fibrotic soft tissue.

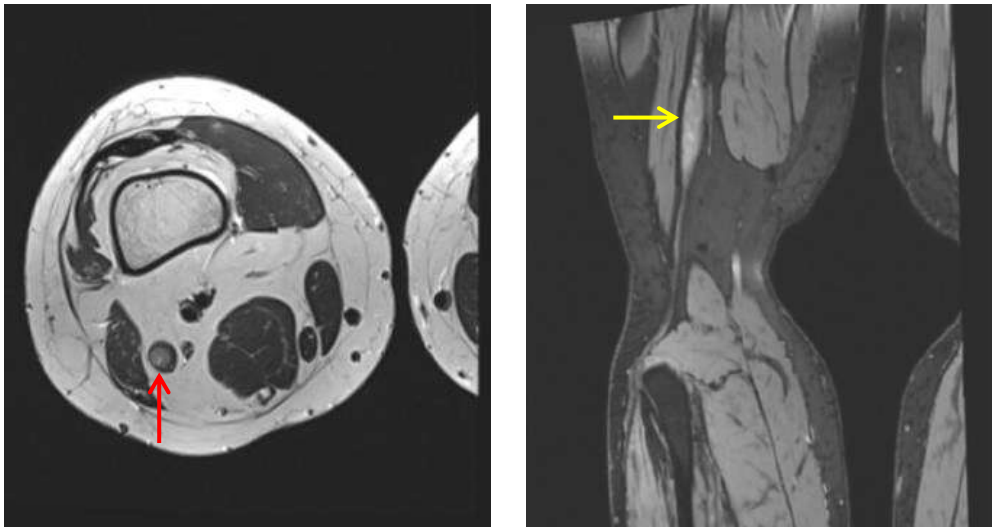


A B

Picture 9:- A 47 year old male with traumatic injury to left brachial plexus underwent MRN examination.

(A) 3D T2 SPACE STIR MIP image shows a pseudomeningocele formation involving intradural segment of left C7 nerve root (curved yellow arrow). C5, C6, C7 and C8 nerve roots, and the trunks of left brachial plexus are thickened and hyperintense (green arrows) as compared to contralateral roots and trunks.

(B) Axial 3D T2 SPACE STIR MIP image shows thickened and hyperintense C5 nerve root and upper trunk of left brachial plexus (red arrow).



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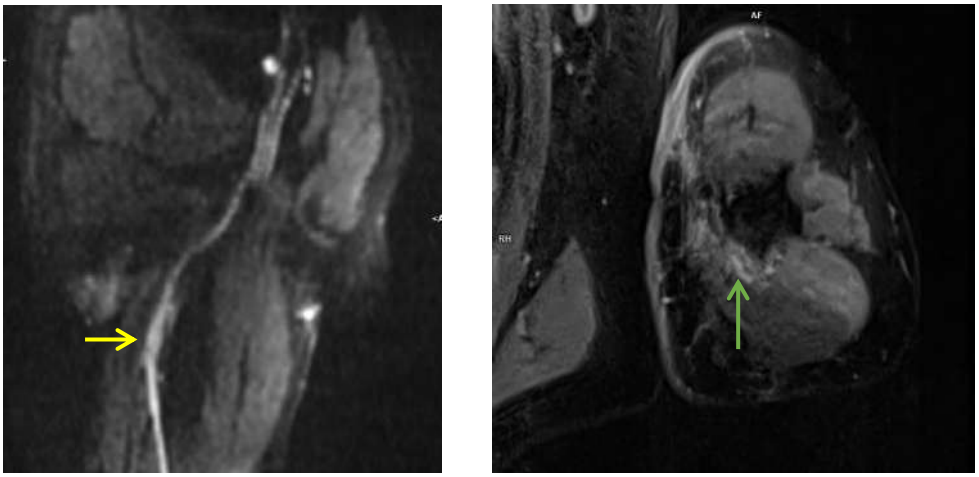
Picture 10:- A 23 old male with H/O road traffic accident and clinical features of foot drop and loss of sensations in the leg and dorsal aspect of foot on right side was evaluated by MRN.

(A) Axial T2 weighted image shows neuroma formation in relation to the origin of right common peroneal nerve (red arrow) in the distal right thigh.

(B) 3D T2 fat sat MIP image shows a spindle shaped hyperintense neuroma (yellow arrow) involving the proximal right common peroneal nerve with thinning of the nerve distal to neuroma.



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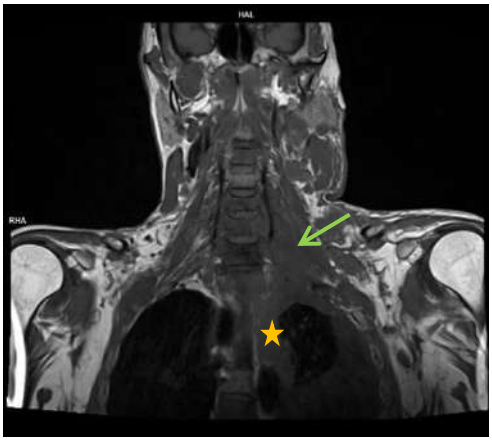
Picture 11:-A 54 year old male with clinical diagnosis of post traumatic left radial nerve palsy underwent MRN examination.

(A) Coronal DWI MIP image shows thickened and hyperintense radial nerve with indistinct outline at the level of lateral head of triceps muscle for a length of approx. 2.0-2.5 cm (yellow arrow).

(B) Axial PD fat sat image at the level of mid arm shows thickened and hyperintense radial nerve with indistinct outline (green arrow)– suggestive of grade II/III left radial nerve injury.



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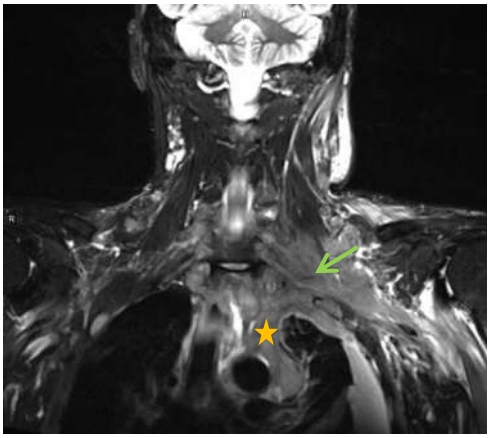

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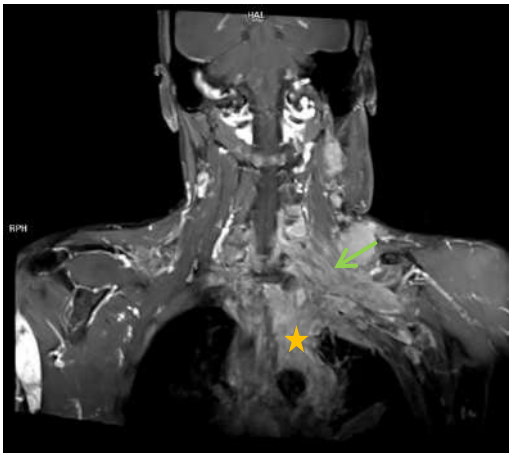

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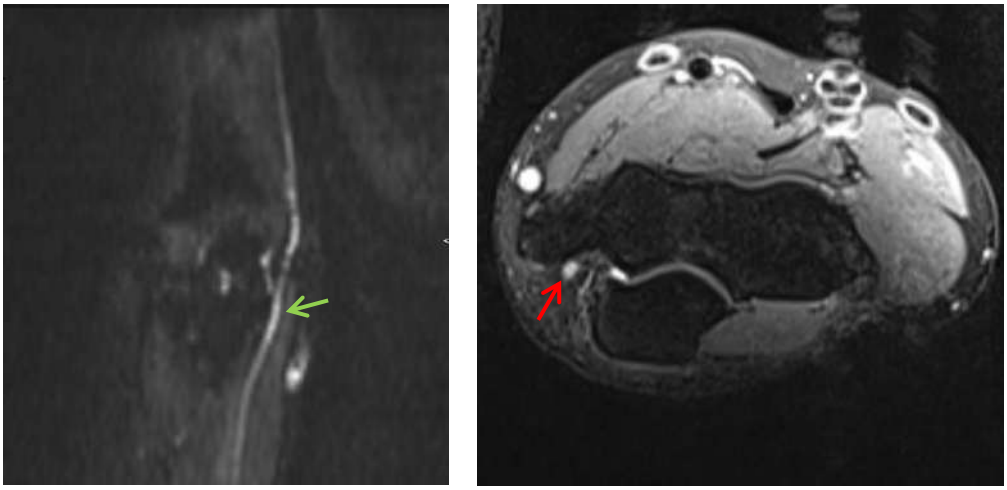
Picture 12:- Biopsy proven case of squamous cell carcinoma with infiltrative soft tissue on left side of neck.
(A) Coronal T1 weighted, (B) Coronal STIR and (C) Coronal T1 post contrast images showing ill defined heterogeneously enhancing soft tissue in left lower cervical region completely encasing trunks, divisions and cords of left brachial plexus (green arrows).
The soft tissue is also seen to infiltrate inferiorly causing encasement of arch vessels and apex of left lung (yellow asterisks).
Imaging findings are in keeping with encasement of left brachial plexus by infiltrative malignant soft tissue.



A B

Picture 13:- A 31 year old male with clinical diagnosis of ulnar nerve compression underwent MRN examination.

(A) Coronal DWI MIP image showing markedly thickened and hyperintense ulnar nerve in the region of cubital tunnel with shaggy outline (green arrow) which is likely secondary to compression of ulnar nerve in the cubital tunnel.

(B) Axial PD fat sat image at the level of elbow shows thickened and hyperintense ulnar nerve posterior to the medial epicondyle (red arrow).

Case no.	Pt Name	MRD	AGE (YEARS)	SEX	Motor Weakness	Sensory Symptoms	MRN Normal/Abnormal	NCV diagnosis	Intraop Findings
1	NK	1536446	4	F	Present	Present	Abnormal	Normal	-
2	K	1527475	2	F	Present	Present	Abnormal	Normal	-
3	SR	1522352	37	M	Present	Present	Abnormal	Abnormal	-
4	SK	1517751	54	M	Present	Present	Abnormal	Abnormal	-
5	RK	1514571	33	M	Present	Present	Abnormal	Abnormal	Complete transection of the radial nerve in the radial groove- in concordance with the MRN findings.
6	KS	1415786	22	M	Present	Present	Abnormal	Abnormal	-
7	SD	1436770	79	F	Absent	Present	Abnormal	Abnormal	-
8	K	1413696	22	F	Present	Present	Abnormal	Abnormal	-
9	KS	1116027	63	M	Absent	Present	Abnormal	Abnormal	-
10	JS	1383629	31	F	Absent	Present	Abnormal	Abnormal	-
11	AD	1377721	37	F	Absent	Present	Abnormal	Abnormal	-
12	ES	928505	23	M	Present	Present	Abnormal	Abnormal	-
13	A	1304431	14	F	Present	Present	Abnormal	Abnormal	-
14	SL	1352129	40	M	Present	Present	Abnormal	Abnormal	-
15	SR	1359052	30	F	Absent	Present	Normal	Normal	-
16	SR	117397	70	F	Present	Absent	Abnormal	Abnormal	-
17	VD	1572523	32	M	Present	Present	Abnormal	Abnormal	Complete transection of the Median nerve at the site of injury - in concordance with MRN findings
18	JS	1432797	23	M	Present	Present	Abnormal	Abnormal	Complete transection of the Median nerve at the site of injury with an overlying hematoma- in concordance with MRN findings
19	JS	1517819	11	M	Present	Present	Abnormal	Abnormal	-
20	D	1570054	31	F	Present	Present	Abnormal	Abnormal	Transection of both branches of bifid Median nerve proximal to carpal tunnel- in concordance with the MRN findings
21	S	207545	52	F	Present	Absent	Abnormal	Abnormal	-
22	M	1697891	43	M	Present	Present	Normal	Normal	-
23	V	1603146	23	M	Present	Present	Abnormal	Abnormal	-
24	RS	1358882	44	M	Present	Absent	Abnormal	Abnormal	-
25	AD	1015011	16	M	Present	Present	Abnormal	Abnormal	-
26	S	893469	47	M	Present	Present	Abnormal	Abnormal	-
27	RM	121778	50	M	Present	Absent	Abnormal	Abnormal	-
28	R	1007946	38	M	Present	Present	Abnormal	Abnormal	-
29	MK	661994	53	F	Absent	Present	Abnormal	Abnormal	-
30	IK	894175	33	F	Absent	Present	Normal	Normal	-
31	A	940306	16	M	Present	Present	Abnormal	Abnormal	-
32	RP	1200475	45	M	Absent	Present	Normal	Abnormal	-
33	IS	825596	62	M	Absent	Present	Abnormal	Abnormal	-
34	D	1201093	25	M	Present	Present	Abnormal	Abnormal	-
35	P	1245901	0.5	F	Present	Absent	Abnormal	Abnormal	-
36	B	915114	54	M	Present	Absent	Abnormal	Abnormal	-
37	S	987212	61	M	Absent	Present	Abnormal	Abnormal	-
38	V	1028941	51	M	Present	Present	Abnormal	Abnormal	-

Case no.	Pt Name	MRD	AGE (YEARS)	SEX	Motor Weakness	Sensory Symptoms	MRN Normal/Abnormal	NCV diagnosis	Intraop Findings
39	H	1257121	27	F	Present	Present	Abnormal	Abnormal	-
40	SS	1194107	17	M	Present	Present	Abnormal	Abnormal	-
41	S	1138551	19	M	Present	Present	Abnormal	Abnormal	-
42	LK	1122988	22	F	Present	Present	Abnormal	Abnormal	-
43	A	238292	16	M	Present	Present	Abnormal	Abnormal	Transection of the radial nerve with few intact fibers in the radial groove - in concordance with MRN findings.
44	HS	904296	40	M	Present	Present	Abnormal	Abnormal	-
45	HK	755147	35	M	Present	Present	Abnormal	Abnormal	-
46	V	1038603	60	F	Absent	Present	Abnormal	Abnormal	-
47	A	786769	51	M	Present	Present	Abnormal	Abnormal	-
48	R	703233	4	M	Present	Present	Abnormal	Abnormal	-
49	S	910662	45	M	Present	Absent	Abnormal	Abnormal	-
50	SK	760795	52	F	Present	Present	Abnormal	Abnormal	-
51	SK	1006098	24	M	Absent	Present	Abnormal	Abnormal	-
52	S	746142	59	F	Present	Absent	Normal	Normal	-
53	MS	747226	28	M	Present	Present	Abnormal	Abnormal	-
54	A	918416	36	F	Absent	Present	Normal	Normal	-
55	A	1187819	24	F	Present	Present	Abnormal	Abnormal	-
56	GB	8473	70	M	Present	Absent	Abnormal	Abnormal	-
57	S	946997	28	M	Present	Present	Abnormal	Abnormal	-
58	JS	1006603	15	M	Present	Present	Abnormal	Abnormal	-

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The Principal
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Ludhiana

Subject:: Approval of Plan of Thesis.

This is to inform you that the Faculty of Medical Sciences in its meeting held on 25.09.2023 has approved the plan of thesis of **Didar Singh**, a student of your college for **MD Radio-diagnosis** along with the names of Supervisor/Co-Supervisor as under:-

Topic Plan of Thesis
Utility of high resolution 3t mr neurography in focal peripheral nerve pathologies .

Supervisor
Dr. Archana Ahluwalia
Professor
Dept. of Radiodiagnosis

Co-Supervisor:-
Dr. Monika Singla
Assoc. Prof.,
Dept. of Neurology

Co-Supervisor:-
Dr. Devinderpal Singh Dhanota
Asst. Professor
Dept. of Radio-diagnosis

The student may submit the thesis in triplicate alongwith the plan in triplicate also, to the Controller of Examinations, BFUHS, Faridkot, at least six months before the commencement of theory examination, if he/she is otherwise eligible to take the examination. He /She may be directed to attach a photocopy of this letter with the forwarding letter while submitting thesis in the University along with the letter of approval of University for change of supervisor/Co-Supervisor, change of topic, if any.

Controller of Examinations

Note :

1. *If any discrepancy found regarding topic of thesis or Supervisor/Co-Supervisor, inform undersigned within one month after issue of this letter.*

UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES

THESIS PROPOSAL

FOR APPROVAL OF SUBJECT OF THESIS TO BE SUBMITTED IN

PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MD

In

RADIODIAGNOSIS

OF THE

BABA FARID UNIVERSITY OF HEALTH SCIENCES

FARIDKOT

JULY, 2022

Dr Didar Singh

DEPARTMENT OF RADIODIAGNOSIS

DAYANAND MEDICAL COLLEGE AND HOSPITAL

LUDHIANA

ABSTRACT OF PLAN OF THESIS

Title	UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES
For the degree of	MD Radiodiagnosis
Name of the candidate	Dr. Didar Singh
Supervisor	Dr. Archana Ahluwalia, Professor, Department of Radiodiagnosis, DMCH, Ludhiana
Co-supervisor(s)	Dr. Monika Singla, Associate Professor, Department of Neurology, DMCH, Ludhiana Dr. Devinderpal Singh Dhanota, Assistant Professor, Department of Radio-diagnosis, DMCH, Ludhiana.
Institution	Dayanand Medical College and Hospital, Ludhiana.
University	Baba Farid University of Health Sciences, Faridkot

Introduction: Extracranial peripheral nerve disorders may be caused by many conditions, including entrapment syndromes, trauma, masses, and acquired and hereditary demyelinating polyneuropathies. Accurate diagnosis of peripheral nerve disorders is important to guide correct patient management. This is usually performed by history taking, clinical examination, and electrodiagnostic studies.[1] However in some cases, clinical and electrodiagnostic studies are indeterminate.[1-2]. MR Neurography (MRN) enables direct visualization of nerves and can aid in diagnosis, characterization, and localization of peripheral nerve disorders.

Aim of study: 1) To evaluate the spectrum of focal peripheral nerve pathologies on MR Neurography 2) To correlate the MR Neurography abnormalities with Nerve Conduction Velocity studies and/or Electromyography findings. 3) To correlate the MR Neurography abnormalities with Surgical and/or Histopathological findings wherever possible.

Materials and Methods: The study will be conducted over a period of one and a half years starting from 15 September 2022 to 8 March 2024 on patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the department of Radiodiagnosis and Imaging, DMCH,Ludhiana.

Clinical Significance: In the past few years, MRN has significantly increased its clinical applications on the basis of three-dimensional or two-dimensional images with and without fat-suppression techniques. MRN may provide information about extent and degree of nerve impairment. MRN can also be applied to selection, planning, and monitoring of surgical procedures that can be performed after traumatic peripheral nerve injuries, such as neurorrhaphy, nerve graft, or neurolysis, as it provides surgeons with valuable information about the functional status of the nerves involved and axonal flow.

Keywords: MR Neurography; Traumatic Nerve Injury; Peripheral Neuropathy.

(Signature) Candidate	(Signature) Supervisor	(Signature) Co-Supervisor	(Signature) Co-Supervisor	(Signature) Principal

CERTIFICATE OF FACILITIES AVAILABLE

This is to certify that the facilities for work on the subject of thesis titled **"UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES "** exist in the Department of Radiodiagnosis, DMC&H, Ludhiana and will be provided to the candidate. We will see that the data being included in the thesis is genuine and is collected by the candidate himself under our supervision and guidance.

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APPROVAL PROFORMA
BY RESEARCH & ETHICAL COMMITTEE
DAYANAND MEDICAL COLLEGE & HOSPITAL, LUDHIANA

Name of candidate	Dr. Didar Singh
Department	Radiodiagnosis
Topic of Thesis	UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES
Likely date of appearing in PG examination	May/June, 2024
Date of enrollment	February 15, 2022
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Dr. Harpreet Kaur (Professor & Head, Pathology)	Mr. R K Sharma (Legal Expert)
Dr. Jaspal Singh (Professor & Head, Surgery)	Dr. Ramit Mahajan (Associate Professor, Gastroenterology)
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	Dr. Gagandeep Singh (Secretary, Ethics Committee Professor & Head, Neurology)

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Dr. Sandeep Puri
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Approved: Yes / ~~No~~

Prof. Arvind Malhotra
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BABA FARID UNIVERSITY OF HEALTH SCIENCES, FARIDKOT

PROFORMA FOR REGISTRATION OF SUBJECT FOR DISSERTATION

1	NAME OF THE CANDIDATE AND ADDRESS	Dr. Didar Singh 1237, Shiv Gali, Namak Mandi, Amritsar, Punjab
2	NAME OF THE INSTITUTE	Dayanand Medical College & Hospital, Ludhiana
3	COURSE OF STUDY AND SUBJECT	M.D. Radiodiagnosis
4	DATE OF ADMISSION OF COURSE	01st March, 2022
5	TITLE OF THE TOPIC	Utility Of High Resolution 3t MR Neurography In Focal Peripheral Nerve Pathologies

6. BRIEF RESUME OF THE INTENDED WORK

6.1 NEED FOR THE STUDY

Peripheral neuropathy, a result of damage to one or more nerves located outside of the brain and spinal cord (peripheral nerves), often causes muscle weakness, numbness, tingling and pain in the affected area , usually in the hands and feet. It can also affect other areas and body functions including digestion, urination and circulation. A common cause of peripheral neuropathy is diabetes, but it can also result from traumatic injuries, infections, peripheral nerve tumors and exposure to toxins. Extracranial peripheral nerve disorders may also be caused by many other conditions, including entrapment syndromes, trauma, masses, and acquired and hereditary demyelinating polyneuropathies. The global prevalence of traumatic peripheral nerve injury is approximately 5%, including brachial and lumbar plexus injuries [3]. Trauma, laceration, or fracture of peripheral nerves can occur more commonly after occupational and motor vehicle accidents, usually involving middle-aged patients [4]. Peripheral nerve trauma is recognised as a potential cause of disability, usually related to decreased muscular strength and loss of proprioceptive and tactile sensations [5]. These lesions most commonly affect the upper limbs, with preferential involvement of the radial and median nerves, in comparison to the lower limbs, where the sciatic and peroneal nerves are the main structures affected [6]. Accurate diagnosis of peripheral nerve disorders is important to guide correct patient management. Evaluation of peripheral nerve pathologies, including peripheral nerve trauma and its post surgical outcome has classically been based on clinical and electrophysiologic methods [7,8]. Clinical evaluation and electrodiagnostic studies provide incomplete information about the anatomy and degree of injury. In particular, these studies are not able to differentiate among Sunderland grade III–V injuries, which is important from a surgical point of view and patient prognosis [9,10]. Many of these patients undergo conservative management. One has to often weigh the benefit versus risk of expectant waiting being cognisant of the fact that in the unfortunate event of poor regenerative response and no recovery, the regional muscles will atrophy and tendon transfers as well as consequent disability will be the only option left for the patient with a poor outcome.. In the clinical arena, there is also an immediate need for reliable quantitative measures that can evaluate peripheral nerve regeneration/further degeneration in patients with traumatic nerve injuries. Proximodistal axonal regeneration is the leading mechanism of recovery from nerve injuries. However, it occurs at a slow pace (~1mm/day), and the

only available clinical tool of “advancing Tinel’s sign” is often unreliable, subjective, and frequently inaccurate. The electrodiagnostic studies are also not sufficient due to their complete dependence on target innervation and lack of interobserver reliability. Therefore, it is crucial for development of a technique that can detect the nerve continuity or neuroma and can be used serially in a noninvasive manner to detect the initiation as well as follow the regeneration in injured axons proximally and across the injury site. Another immediate clinical and preclinical need for noninvasive outcome measurement of nerve regeneration is in the area of therapeutics aiming to enhance nerve growth in injuries and mono-/polyneuropathy conditions. Also the non traumatic peripheral nerve pathologies are needed to be evaluated in a more precise and objective manner. Ultrasound and MRI are the main imaging modalities for peripheral nerve evaluation [11,12]. However, Ultrasound shows limited reproducibility compared with MRI, as it depends on operator skills, requiring expertise to achieve an accurate diagnosis of peripheral nerve injury [13]. High field (3 Tesla, T) imaging employing high resolution MR Neurography (MRN) techniques is an important noninvasive modality that can both detect as well as help to grade nerve injuries, ultimately assisting in diagnostic and therapeutic workup of patients having peripheral nerve pathologies. MRN enables evaluation of the whole path of almost any peripheral nerve in a more reproducible manner than Ultrasound. Also, MRN has fewer limitations for assessing deep or difficult anatomic areas such as the lumbar plexus [14], and the same study allows evaluation of bone and soft tissue including muscles, which may show signs of denervation injury [15]. 3D Fat Sat and Diffusion images are also very useful for surgical planning. MRN has also been proposed as a useful tool for assessment of post surgical outcomes and complications in patients who have undergone surgical repair of peripheral nerve injuries [11,16,17]. MRN has been successfully used to confirm clinical suspicion of peripheral neuropathy by directly showing the nerve abnormality or regional muscle denervation changes; to assess the extent of the abnormality in nerve injuries or the disease load in diffuse peripheral nerve lesions, such as hereditary neuropathies and neurofibromatosis; to depict the lesions causing nerve entrapment or impingement; to exclude the diagnosis of neuropathy by showing normal nerves and regional muscles; and to detect incidental lesions in the region of interest that mimic neuropathy symptoms.

6.2 REVIEW OF LITERATURE

Electrodiagnostic studies, which include electromyography(EMG) and nerve conduction examinations, have been widely considered the reference method for the diagnosis of peripheral neuropathy in the past. However there are certain limitations of these electrodiagnostic studies, which include; more time consuming to perform; may provide indeterminate results, especially in postoperative cases because of the long delay of electrical signals to return; may be uncomfortable for patients; or may even be unfeasible in subjects with dermatologic diseases and in cases of inaccessible deeply situated nerves [18,19].

MR Neurography (MRN) and ultrasound were introduced in the 1980s as noninvasive techniques that could address some of the aforementioned issues [20-22]. Ultrasound remains operator dependant and nerve imaging may be degraded by dense scarring and shadowing from surrounding calcifications.

Historically, compared with an electro- diagnostic study, MR Neurography exhibited good diagnostic accuracy [23].

Currently, the increasing use of 3-T MR scanners, new phased- array surface coils, and parallel imaging aids in the acquisition of high-resolution and high contrast images in short imaging times, and other limitations of the low field strength scanners have also been overcame to a significant extent. On the basis of clinical and electrodiagnostic study findings, referring physicians are usually able to determine the anatomic area to be imaged. In certain cases, however, this preselection is not possible. In those cases, multiple areas of the body can be quickly screened using MRI.

Various studies have been done in the past to demonstrate the role of MR Neurography in peripheral nerve disorders: Kevin R. Moore et. al. (2001) have done a prospective study on fifteen patients who presented with neuropathic leg pain. All of these patients underwent high-resolution MR neurography. Thirteen of the patients also underwent routine MR imaging of the lumbar segments of the spinal cord before undergoing MR neurography. Using phased-array surface coils, they performed MR neurography with T1-weighted spin-echo and fat-saturated T2-weighted fast spin-echo or fast spin-echo inversion recovery sequences, which included coronal, oblique sagittal, and/or axial views. The lumbosacral plexus and/or sciatic nerve were identified using anatomic location, fascicular morphology, and signal intensity as discriminatory criteria. They observed that none of the routine MR imaging studies of the lumbar

segments of the spinal cord established the cause of the reported symptoms. Conversely, MR neurography showed a causal abnormality accounting for the clinical findings in all 15 cases. Detected anatomic abnormalities included fibrous entrapment, muscular entrapment, vascular compression, post traumatic injury, ischemic neuropathy, neoplastic infiltration, granulomatous infiltration, neural sheath tumor, post radiation scar tissue, and hypertrophic neuropathy. They concluded that for patients with neuropathic leg pain resulting from extraforaminal lesions, the cause of the pain generally will not be revealed by routine MR imaging of the lumbar segments of the spinal cord. Conversely, MR neurography is a sensitive diagnostic imaging technique for evaluating both the lumbosacral plexus and sciatic nerve [24].

Martin Bendszus et. al. (2003) have done a prospective study of 40 consecutive patients clinically presenting with a foot drop to evaluate the utility of MR imaging in the diagnosis of neurogenic muscle disorders compared with that of clinical and electrophysiologic examination. In this study, MR imaging of the lower leg included axial T1-weighted and axial turbo inversion recovery magnitude (TIRM) sequences. Two readers blinded to clinical data evaluated T1-weighted images for anatomic localization of affected muscles and TIRM images for patterns of signal intensity increase. After MR imaging, a detailed neurophysiologic examination was per- formed. Cause of foot drop was independently determined on the basis of MR and electrophysiologic data.

They observed that clinical examination and electromyography (EMG) disclosed 20 peroneal nerve lesions, nine cases of L5 radiculopathy, and 11 nerve lesions extending beyond neural structures. MR imaging revealed three distinct patterns of signal intensity increase on TIRM images: peroneal nerve pattern, L5 pattern, and unspecific pattern. MR imaging and EMG findings were in agreement in 37 (92%) of 40 patients. In three patients, MR imaging revealed a more widespread involvement than did EMG. In one of these patients, denervation in the corresponding muscle was validated by follow-up EMG. No false negative diagnoses were made by use of MR imaging as compared with use of EMG. They concluded that MR imaging improves accuracy in the differential diagnosis of peripheral nerve lesions compared with that of EMG and can supplement EMG in the diagnosis of denervated muscles [25].

Philipp Bäumer et. al.(2011) have done a prospective study to assess nerve T2 signal and caliber as diagnostic signs at magnetic resonance (MR) neurography in ulnar neuropathy at the elbow (UNE). Twenty patients with UNE were graded by using

clinical criteria and nerve conduction studies as mild (n = 12) and severe (n = 8) and were compared with 20 healthy control subjects. All subjects underwent ulnar nerve MR neurography (in-plane resolution of 0.4 3 0.4 mm) covering the elbow region, including T2-weighted imaging with fat suppression (turbo inversion-recovery magnitude sequence: repetition time msec/ echo time msec/ inversion time msec, 6, 120/66/180) and T1-weighted turbo spin-echo imaging (843/16). Nerve T2 signal increase, mea- sured by using T2-weighted contrast to-noise ratios across the cubital tunnel, and nerve caliber, determined by using T1-weighted pixel-wise measurement of cross-sectional nerve area, were evaluated as diagnostic signs. Qualitative assessment by using visual grading was performed additionally. They observed that diagnostic performance, as determined with area under the receiver operating characteristic curve (AUC), was excellent for nerve T2 signal to discriminate UNE from a normal finding (AUC = 0.94; 95% confidence interval [CI]: 0.87, 1.00) and was excellent for nerve caliber to discriminate severe from mild UNE (AUC = 0.95; 95% CI: 0.85, 1.00). Qualitative assessment demonstrated sensitivity of 83% and specificity of 85% for MR neurography of UNE. They concluded that nerve T2 signal increase seems to be an accurate sign to determine the presence of UNE. Nerve caliber enlargement discriminates severe from mild UNE. UNE may be diagnosed with high accuracy by means of quantitative or qualitative evaluation of these signs [26].

Roman Guggenberger, Daniel Markovic et. al. (2012) have done a prospective case control study on 60 individuals to compare normative diffusion values of the median nerve at several anatomic locations in healthy men and women of variable age with those in patients with carpal tunnel syndrome. After ethics board approval and written informed consent were obtained, 45 healthy volunteers (30 women, 15 men) and 15 patients (10 women, five men) were studied. Volunteers were divided into three age groups. Magnetic resonance (MR) neurography with diffusion-tensor imaging (DTI) was performed in all study participants at 3.0 T by using a singleshot echo-planar imaging sequence (repetition time msec/echo time msec, 10123/40; b = 1200 sec/ mm2). Fractional anisotropy (FA) and apparent diffusion coefficient (ADC) of the median nerve were determined by two readers at three locations: the levels of the distal radioulnar joint, pisiform bone, and hamate bone. They observed that Normative FA and ADC values were calculated for men and women, different age groups, and different anatomic locations. FA and ADC did not differ between men and women (P = .28 and P = .38, respectively). FA decreased and ADC increased when moving from

proximal to distal locations (P < .001). FA decreased and ADC increased significantly with age (P < .001). There was a significant difference between healthy volunteers and patients with carpal tunnel syndrome (P < .001 for both FA and ADC). An FA threshold of 0.47 and an ADC threshold of 1.054 x 10^-3 mm2/ sec might be used in the diagnosis of carpal tunnel syndrome. They concluded that Normative diffusion values for MR neurography of the median nerve with DTI depend on the anatomic location and age but not on sex. Age-specific FA and ADC threshold values might be used to diagnose carpal tunnel syndrome [27].

A.Chhabra et. al. (2013) have done a prospective study on twenty nine patients to evaluate the role of 3T anatomic MR imaging and DTI in the characterization of peripheral nerve tumor and tumorlike conditions. Twenty-nine patients (13 men, 16 women;mean age,41+/-18years; range,11–83 years) with a nerve tumor or tumorlike condition (25 benign, 5 malignant) underwent 3T MR imaging by using anatomic (n = 29), functional diffusion, DWI (n =21), and DTI (n = 24) techniques. Images were evaluated for image quality (3-point scale), ADC of the lesion, tractography, and fractional anisotropy of nerves with interobserver reliability in ADC and FA measurements.

They observed that No significant differences were observed in age (benign,40+/-18 versus malignant,45+/-19years) and sex (benign, male/female= 12:12 versus malignant, male/female = 3:2) (P > .05). All anatomic (29/29, 100%) MR imaging studies received “good” quality; 20/21 (95%) DWI and 21/24 (79%) DTI studies received “good” quality. ADC of benign lesions (1.848 +/- 0.40 x 10^-3 mm2/s) differed from that of malignant lesions (0.900 +/- 0.25 x 10^-3 mm2/s, P < .001) with excellent inter observer reliability (ICC = 0.988 [95% CI, 0.976–0.994]). There were no FA or ADC differences between men and women (P > .05). FA of involved nerves was lower than that in contralateral healthy nerves (P < .001) with excellent inter observer reliability (ICC = 0.970 [95% CI, 0.946 – 0.991]). ADC on DTI and DWI was not statistically different (P > .05), with excellent inter method reliability (ICC = 0.943 [95% CI, 0.836 – 0.980]). Tractography differences were observed in benign and malignant lesions. They concluded that 3T MR imaging and DTI are valuable methods for anatomic and functional evaluation of peripheral nerve lesions with excellent inter observer reliability. While tractography and low FA provide insight into neural integrity, low diffusivity values indicate malignancy in neural masses[28].

Xinzeng Wang et. al. (2016) have done a prospective study on five healthy volunteers and 10 patients of brachial plexopathy to develop and evaluate magnetic resonance MR neurography of the brachial plexus with robust fat and blood suppression for increased conspicuity of nerves at 3.0 T in clinically feasible acquisition times. A low-refocusing-flip-angle three-dimensional (3D) turbo spinecho (TSE) sequence was modified to ac- quire both in-phase and out-of- phase echoes, required for chemical shift (Dixon) reconstruction, in the same repetition by using partial echoes combined with modified homodyne reconstruction with phase preservation. The sequence was tested in five healthy volunteers and was evaluated in 10 patients who had been referred for brachial plexopathy at 3.0 T. The images were evaluated against the current standard of care, images acquired with a 3D TSE short inversion time inversion recovery (STIR) sequence, qualitatively by using the Wilcoxon signed-rank test and quantitatively by using the Friedman two-way analysis of variance, with $P < 0.05$ considered to indicate a statistically significant difference.

They observed that Multiecho TSE-mDixon involving partial-echo and homodyne reconstruction with phase preservation achieved uniform fat suppression in half the imaging time compared with multiacquisition TSEmDixon. Compared with 3D TSE STIR, fat suppression, venous suppression, and nerve visualization were significantly improved (P , .05), while arterial suppression was better but not significantly so (P = .06), with increased apparent signal-to- noise ratio in the dorsal nerve root ganglion and C6 nerve (P , .001) with the multiecho TSE-mDixon sequence. They concluded that the multiecho 3D TSE-mDixon sequence provides robust fat and blood suppression, resulting in increased conspicuity of the nerves, in clinically feasible imaging times and can be used for MR neurography of the brachial plexus at 3.0 T [29].

J.L. Chazen et. al. (2018) have done a retrospective study to evaluate the utility of MR neurography in lumbosacral radiculopathy and correlate abnormal intraneural signal with history, physical examination, and abnormal electrodiagnostic study findings. Retrospective review of 64 lumbosacral MR neurography examinations performed from December 2014 through January 2017 on a 3T scanner was undertaken. MR neurography examinations were independently reviewed in a blinded fashion by 2 radiologists, and the intraneural signal was graded on a 0 – 2 scale relative to adjacent vasculature. Abnormal nerve signal was correlated with subjective and objective findings from clinical notes in the electronic medical record and compared with results of electrodiagnostic studies (nerve conduction study/electromyography). They

observed that Twenty- nine (45%) MR neurography examinations had abnormal intraneural signal. There was no statistically significant correlation between subjective clinical findings and intraneural signal abnormality on MR neurography. There was a statistically significant correlation between abnormal intraneural T2 signal and findings of active radiculopathy on electromyography ($P < 0.001$). They concluded that Lumbosacral MR neurography appears to demonstrate abnormal intraneural signal in a substantial portion of patients with clinical symptoms of lower extremity radiculopathy and correlates with findings of active radiculopathy on electromyography. This finding further bolsters the growing body of evidence on the utility of MR neurography and suggests that abnormal intraneural signal may provide a useful adjunct to electrodiagnostic testing. Further research is required to evaluate the prognostic value of MR neurography, which may help guide therapeutic decision-making [30].

6.3 AIMS AND OBJECTIVES OF THE STUDY

1. To evaluate the spectrum of focal peripheral nerve pathologies on MR Neurography.
2. To correlate the MR Neurography abnormalities with Nerve Conduction Velocity studies and/or Electromyography findings.
3. To correlate the MR Neurography abnormalities with Surgical and/or Histopathological findings wherever possible.

7.0 MATERIALS AND METHODS:

The study will be conducted over a period of one and a half years starting from 15 September 2022 to 8 March 2024 on patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the department of Radiodiagnosis and Imaging, Dayanand Medical College and Hospital, Ludhiana.

7.1 SOURCE OF DATA

A prospective study will be done over a period of one and a half year starting from 15 September 2022 to 8 March 2024 on patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to the Department of Radiodiagnosis and Imaging at Dayanand Medical College and Hospital, Ludhiana.

7.2 METHOD OF COLLECTION OF DATA

Inclusion Criteria

1. All patients with clinical diagnosis of focal peripheral nerve pathology referred for MR Neurography to Dayanand Medical College and Hospital, Ludhiana.

Exclusion Criterion

1. Patients not willing for the study
2. Patients who have already been operated for some peripheral nerve disorder.
3. Patients having metallic foreign body implants.
4. Patients having implanted cardiac pacemaker, or insulin pumps, or gastric reflux device.

MR imaging technique

Patient will be examined on MAGNETOM SKYRA 48 Channel 3 Tesla MRI Scanner by Siemens, Germany after taking informed consent in his/her vernacular language before making him/her part of the study and relevant history will be elicited from each patient. The following MRI sequences will be taken of the area of interest/injury and will be analysed:

Sequence	T1 TSE Transverse	T2 TSE Transverse	PD-FS TSE Transverse	3D T2 SPACE STIR COR	3D DWI Transverse	T2 3D DIXON	COR STIR
Acquisition time	03:40 min	03:50 min	03:10 min	03:54 min	02:20 min	06:00 min	03:46 min
Orientation	Transverse	Transverse	Transverse	Coronal	Transverse	Coronal	Coronal
Resolution Matrix	320* 100	448* 81	320* 80	384* 60	128* 91	256* 65	384* 75
No. of slices	30	30	30	96/slab	30	160/slab	80/slab
FoV Read (mm)	170	170	170	380	260	150	330
FoV Phase (%)	100	100	100	60.4	68.8	100	59.4
Slice Thickness (mm)	3	3	3	1.5	3	0.6	1.5
Slice Gap (mm)	1	1	1	1	1	1	1
Repetition Time (msec)	920	5000	4710	3000	8060	14.1	5160
TE (msec)	21	71	24	283	57	5	61
Flip Angle	147	140	150	—	—	25	160
Flow Compression	No	No	Read	No	—	No	Read

DURATION OF STUDY- 1.5 years starting from 15 September 2022 to 8 March 2024.

STATISTICAL ANALYSIS

Data were described in terms of range; mean ±standard deviation (± SD, frequencies (number of cases) and relative frequencies (percentages) as appropriate.For

comparing categorical data, Chi square ($\chi 2$) test was performed and fisher exact test was used when the expected frequency is less than 5. Sensitivity, specificity, accuracy, positive predictive value, and negative predictive value were also calculated. A probability value (*p* value)less than 0.05 was considered statistically significant.All statistical calculations were done using SPSS (Statistical Package for the Social Science) SPSS 21version(SPSS Inc., Chicago, IL, USA)statistical program for Microsoft Windows.

OUTCOME:

To analyse the role of MR Neurography in clinical management of patients with focal peripheral nerve pathologies.

7.3 DOES THE STUDY REQUIRE ANY INVESTIGATIONS OR INTERVENTIONS TO BE CONDUCTED ON PATIENTS OR OTHER HUMANS OR ANIMALS? IF SO, PLEASE DESCRIBE BRIEFLY.

No.

7.4 HAS ETHICAL CLEARANCE BEEN OBTAINED FROM YOUR INSTITUTION IN CASE OF 7.3?

Attached herewith

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PROFORMA

Sr. No.

Name:

Age/Sex:

MRD no.:

Address:

Contact no.:

Chief complaints:

Past history:

General Physical Examination:

CNS Examination:

1) Cranial Nerves examination:

2) Higher mental functions

	Yes	**No**
Conscious		
Oriented to time place and person		
Memory intact		

3) Cerebellar examination:

Test	**Result**	
	Positive	Negative
Cerebellar dysfunction signs		

Examination of muscles of the upper limbs			
Action	**Muscle**	**Nerve, nerve roots**	**Weakness present or absent**
Shoulder			
Abduction	Supraspinatus	Suprascapular (C5,C6)	
External rotation	Infraspinatus	Suprascapular (C5,C6)	
Abduction, Extension	Deltoid	Axillary(C5,C6)	
Adduction of arms with shoulder flexed	Pectoralis major	Pectoral nerves (C5,C6,C7,C8)	
Lateral and forward movement and fixation of the scapula	Serratus anterior	Long thoracic (C5,C6,C7)	
Elbow			
Flexion	Biceps	Musculocutaneous (C5,C6)	
Extension	Triceps	Radial (C6,C7)	
Wrist			
Extension, abduction	Extensor carpi radialis longus (ECRL)	Radial (C6,C7)	
Extension, adduction	Extensor carpi ulnaris (ECU)	Posterior interosseous (C7,C8)	
Flexion, abduction	Flexor carpi radialis(FCR)	Median (C6,C7)	

Flexion, adduction	Flexor carpi ulnaris(FCU)	Ulnar (C7,C8,T1)	
Fingers			
Extension	Extensor digitorum communis	Posterior interosseous (C7,C8)	
Flexion	Flexor digitorum profundus	F2, F3: anterior interosseous, (C7, C8, T1) F4, F5: ulnar, (C7, C8, T1)	
Thumb abduction	Abductor pollicis brevis	Median (C8,T1)	
Abduction of the index finger	First dorsal interosseous muscle	Ulnar (C8,T1)	

Examination of muscles of the lower limbs			
Action	**Muscle**	**Nerve(s), Nerve roots**	**Weakness present or absent**
Hip			
Flexion	Iliopsoas	Lumbar plexus,femoral (L1,L2,L3)	
Extension	Gluteus maximus	Inferior gluteal(L5,S1,S2)	
Adduction	Adductor Magnus,longus and brevis	Obturator(L2,L3,L4)	
Abduction	Gluteus medius, Gluteus minimus	Superior gluteal (L4,L5,S1)	
Knee			
Extension	Quadriceps femoris	Femoral(L2,L3,L4)	
Flexion	Hamstrings	Sciatic(L4,L5,S1,S2)	
Ankle			
Dorsiflexion	Tibialis anterior	Deep peroneal(L4,L5)	
Inversion	Tibialis posterior	Tibial(L5,S1)	
Eversion	Peroneus longus and brevis	Superficial peroneal(L5,S1)	
Plantarflexion	Medial and lateral gastrocnemius; Soleus	Tibial (L5,S1,S2)	

Sensory examination of the affected area

Affected area/Area of interest:

Sensation	Present	Absent
Pain		
Temperature		
Touch		
Pressure		
Vibration		

Action	Muscle	Nerve(s), Nerve roots	Weakness present or absent
Toes			
Big toe extension	Extensor hallucis longus	Deep peroneal (L5,S1)	
Extension of other toes	Extensor digitorum longus and brevis	Deep peroneal (L5,S1)	
Flexion	Flexor digitorum longus; Flexor hallucis longus	Tibial (L5,S1)	

MR Neurography findings:

NCV/EMG diagnosis:

Surgical/HPE findings(if applicable):

Final diagnosis:

Concordance:

Present	Absent

INFORMED PATIENT CONSENT

Date: _____

I……..D/o, W/o, S/o……. am willing to participate in the study "**UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES** " The procedure with its complications has been explained to me in local vernacular language. I have fully understood that no special tests and extra expenditure in any form, merely for the purpose of thesis is being carried out. I am free to opt out the study any time without assigning any reason.

……. ……

Signature of the Witness Signature of the patient

Name:

Signature of Candidate Signature of Supervisor

मरीज अनुमति फार्म

तिथि _____

मैं _____ पत्नी/पुत्र/पुत्री _____ निवासी _____ इस शोधकार्य "**UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES** " में भाग लेने के लिए सहमत हूँ। मैं इस शोधकार्य में भाग लेने के लिए अपनी स्वेच्छा से तैयार हूँ। मैं पुष्टि करता/करती हूँ की यह स्वीकृति देने के लिए मुझे कोई आर्थिक प्रलोभन नहीं दिया गया और न ही दबाव डाला गया है। मुझे इस शोधकार्य का उद्देश्य स्पष्ट कर दिया गया है और मुझे यह विश्वास है की यह विज्ञान और मानवता के लाभ के लिए है। मुझे इस शोधकार्य में होने वाले जोखिम के बारे में समझा दिया गया है और मेरी समझ में यह जोखिम बहुत मामुली है।

मैं इस शोधकार्य में भाग लेने के सम्बन्ध में किसी भी समय अपनी अस्वीकृति व्यक्त कर सकता/सकती हूँ और मेरे अस्वीकृति व्यक्त करने का मेरे इलाज पर कोई प्रभाव नहीं पड़ेगा।

_____ _____

गवाह के हस्ताक्षर रोगी के हस्ताक्षर/अंगूठे का निशान

नाम: नाम:

_____

अन्वेषक केहस्ताक्षर

_____

विद्यार्थी के हस्ताक्षर

ਮਰੀਜ਼ ਰਜ਼ਾਮੰਦੀ ਫਾਰਮ

ਮਿਤੀ_____

ਮੈ_____ ਪਤਨੀ/ਪੁੱਤਰ/ਪੁੱਤਰੀ_____ ਵਾਸੀ _____ “**UTILITY OF HIGH RESOLUTION 3T MR NEUROGRAPHY IN FOCAL PERIPHERAL NERVE PATHOLOGIES** ” ਤੇ ਚਲ ਰਹੀ ਖੋਜ ਵਿਚ ਹਿੱਸਾ ਲੈਣ ਲਈ ਰਜ਼ਾਮੰਦ ਹਾਂ। ਇਸ ਖੋਜ ਕੰਮ ਵਿਚ ਹਿੱਸਾ ਲੈਣ ਲਈ ਮੈ ਆਪਣੀ ਮਰਜ਼ੀ ਨਾਲ ਤਿਆਰ ਹਾਂ। ਮੈ ਇਹ ਦਸਣਾ ਚਾਹੁੰਦਾ ਹਾਂ/ ਚਾਹੁੰਦੀ ਹਾਂ ਕੇ ਇਹ ਰਜ਼ਾਮੰਦੀ ਦੇਣ ਵਾਸਤੇ ਮੈਨੂ ਕਿਸੇ ਵੀ ਤਰਾਂ ਦਾ ਲੋਭ ਲਾਲਚ ਨਹੀ ਦਿੱਤਾ ਗਿਆ ਅਤੇ ਨਾਹੀ ਕੋਈ ਦਬਾ ਪਾਇਆ ਗਿਆ ਹੈ। ਮੈਨੂ ਇਸ ਖੋਜ ਦਾਮਨੇਰਥ ਸਮਝਾ ਦਿੱਤਾ ਗਿਆ ਹੈ ਅਤੇ ਮੈਨੂ ਇਹ ਭਰੋਸਾ ਦਵਾਇਆ ਗਿਆ ਹੈ ਕੇ ਇਹ ਖੋਜ ਵਿਗਿਆਨ ਅਤੇ ਮਾਨਵਤਾ ਦੀ ਭਲਾਈ ਲਈ ਹੈ। ਮੈਨੂ ਇਸ ਖੋਜ ਵਿਚ ਹੋਣ ਵਾਲੇ ਖਤਰੇ ਬਾਰੇ ਸਮਝਾ ਦਿੱਤਾ ਗਿਆ ਹੈ ਅਤੇ ਮੈਨੂ ਇਹ ਯਕੀਨ ਹੈ ਕੇ ਇਹ ਖਤਰਾ ਬਹੁਤ ਮਾਮੂਲੀ ਹੈ। ਮੈਨੂ ਇਸ ਖੋਜ ਕੰਮ ਵਿਚ ਹਿੱਸਾ ਲੈਣ ਦਾ ਢੰਗ–ਤਰੀਕਾ ਸਮਝਾ ਦਿੱਤਾ ਗਿਆ ਹੈ।

ਮੈ ਇਸ ਖੋਜ ਕੰਮ ਵਿਚ ਹਿੱਸਾ ਲੈਣ ਬਾਰੇ ਆਪਣੀ ਰਜ਼ਾਮੰਦੀ ਕਿਸੇ ਵੀ ਸਮੇ ਵਾਪਸ ਲੈ ਸਕਦਾ ਹਾਂ/ ਸਕਦੀ ਹਾਂ ਅਤੇ ਮੇਰੀ ਰਜ਼ਾਮੰਦੀ ਵਾਪਸ ਲੈਣ ਦਾ ਮੇਰੇ ਇਲਾਜ ਤੇ ਕੋਈ ਅਸਰ ਨਹੀ ਹੋਵੇਗਾ।

_____ _____

ਗਵਾਹ ਦੇ ਹਸਤਾਖਰ ਮਰੀਜ਼ ਦੇ ਹਸਤਾਖਰ

ਮਿਤੀ_____ ਮਿਤੀ_____

ਪਤਾ _____ ਪਤਾ _____

_____

ਨਿਰੀਖਕ ਦੇ ਹਸਤਾਖਰ

_____

ਸਿਖਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ